

*A thought which does not result in an action is nothing much,
and an action which does not proceed from a thought is nothing at all.*

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(French writer, 1888-1948)

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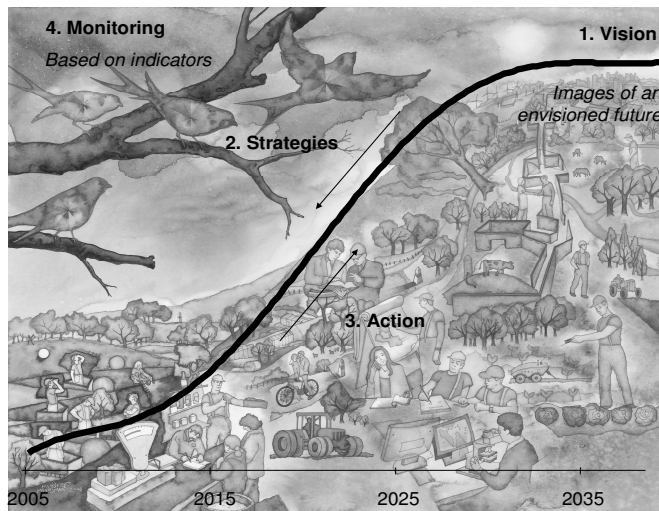
Concretisation and operationalisation of ecological sustainability
of Flemish farms

Thesis submitted in fulfillment of the requirements for the
degree of Doctor (PhD) in Applied Biological Sciences

Dutch translation of the title:

Concretisering en operationalisering van ecologische duurzaamheid van Vlaamse landbouwbedrijven

Cover: 'Sustainable agriculture' captured in one drawing



The drawing visualises the different steps of a transition framework, that considers sustainable development as a complex, drastic and long-term process of change (schematic overview in Figure 1.1). Source: Steunpunt Duurzame Landbouw, 2006.

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Voorwoord / Preface

No man is so foolish but may give another good counsel sometimes; and no man is so wise but may easily err, if he will take no others' counsel but his own. But very few men are wise by their own counsel, or learned by their own teaching. For he that was only taught by himself had a fool to his master.

Benjamin Jonson
(English dramatist, 1572–1637)

Ik vind het nog altijd een beetje raar, mijn eigen doctoraat... Ik heb de voorbije vijf jaar nooit echt het gevoel gehad dat ik 'aan het doctoreren' was, het is er precies zowat vanzelf gekomen. Alhoewel, dat vanzelf komen klopt toch niet helemaal; ik had dit eindpunt nooit bereikt zonder hulp, goede raad, begeleiding, vertrouwen en vriendschap van heel wat mensen. Ik wil dan ook iedereen die van ver of van dicht bij dit onderzoek is betrokken geweest oprecht bedanken, en in het bijzonder volgende personen:

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Diane Schoonhoven, bedankt voor de noodzakelijke gegevens. Het toepassen van de indicatoren op de 20 praktijkbedrijven in het Leader+ project 'Sterk met

Melk' was essentieel voor dit onderzoek. Bedankt aan de mensen van het Instituut voor Natuur- en Bosonderzoek voor de gegevens en de hulp bij het biodiversiteitsonderzoek. Bedankt ook aan alle deelnemers aan de verschillende klankbordgroepen voor hun inzet en interesse.

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Ik wil graag mijn vrienden en familie bedanken voor de leuke bezoeken en uitstapjes en de ontspannende gesprekken over de essentiële dingen des levens (kinderen, huizen, tuinen, vakanties...).

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Marijke

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Chapter 1

Introduction, objectives and outline



Introduction, objectives and outline

1.1. Introduction

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). This 'Brundtland-definition' is known worldwide, and has rightfully gained its place in the vision, mission and strategy of companies, organizations and governments. Also in agriculture, the idea of sustainability has been introduced, proof of which is the fundamental reform of the European agricultural policy in 2003: where the emphasis of the early Common Agricultural Policy (CAP) was to encourage better productivity in the food chain, an important objective of today's CAP is to 'have a sustainable, efficient farming sector which uses safe, clean, environmentally-friendly production methods providing quality products to meet consumers' demands' (European Commission, 2004).

Also in Flanders, the local government as well as farmer's organisations embrace sustainability as a principle, an attitude which is undoubtedly inspired by a certain 'sense of urgency' (Nevens et al., 2007). It is clear that Flemish agriculture faces a number of ongoing trends that are understood to be untenable and unsustainable: a persistent excess of nutrient and pesticide losses to ground and surface waters, a significant loss of biodiversity in rural areas, a comparably low and unsustainable farmer's income, unanswered societal claims, farmers' stress related problems, etc. These are exemplary aspects that create a burning platform for current agricultural systems and that urge towards a changed, adapted or radically innovative, more sustainable farming.

But what exactly is sustainable farming and what constitutes a sustainable farm? And what are the actual management decisions farmers need to take to make their farms (more) sustainable? Putting the theoretical concept into practice, into actual measures and actions towards adapted and/or new farming systems, often proves to be very difficult.

1.2. Research objectives

The objective of this thesis is to address the 'sustainability-paradox' between intention and action, by trying to outline the actual topics in play for sustainable Flemish farms, to establish objective yet achievable goals and develop a set of

relevant indicators. **Hence, the first major objective is to make 'sustainability' concrete on Flemish farms.**

Many methods have already been developed to identify and evaluate sustainability, also in agriculture. Often, these methods involve indicator-based monitoring tools, since these have been found effective for sustainability assessments (Bell and Morse, 1999; Bossel, 1999). Examples are 'visual integration' tools, aggregating values of a balanced set of relevant sustainability indicators into radar graphs (Bockstaller et al., 1997; Rigby et al., 2001) or bar graphs (Lewis and Bardon, 1998); and 'numerical integration' tools, aggregating indicator values into a single composite index (e.g. Taylor et al, 1993; Van Passel et al., 2007). An elaborate literature review of approaches to assess sustainability is provided by Van Passel (2007).

However, despite this extended literature on sustainability monitoring tools, there is still a large gap concerning the logical next step, i.e. can these evaluations effectively be used, in practice, to make agriculture more sustainable and if so, how? And perhaps even more importantly, are farmers actually willing to use the monitoring tools that have been developed? **A second major objective of this thesis is to make 'sustainability' operational¹ on Flemish farms.**

1.2.1. Concretisation of sustainability

A useful tool to effectively solve the 'sustainability-paradox' between theory and practice, is a framework that considers sustainable development as a long-term, complex and drastic process of change (a 'transition'; Rotmans, 2003; Geels, 2005). This framework comprises four actions (Figure 1.1): (i) developing a vision, (ii) establishing one or more strategies, (iii) taking action and (iv) monitoring progress. A vision describes images of an envisioned, sustainable future. Strategies align possible paths to reach the intended goals as defined by the envisioned future; they serve as a decision-base for taking actions. Finally, a monitoring instrument is used to follow up whether running or anticipated actions actually contribute to achieve the objectives defined by the vision. Within this transition framework, a monitoring instrument is an essential tool to make sustainability concrete at the most practical level.

To make sustainability concrete at Flemish farms, we develop a monitoring tool that allows the translation of sustainability (as defined by the vision) in concrete themes and indicators and that can be used to measure sustainability of Flemish farms.

¹ 'Operational' is used here in the sense of 'being in effect' or 'being in operation'

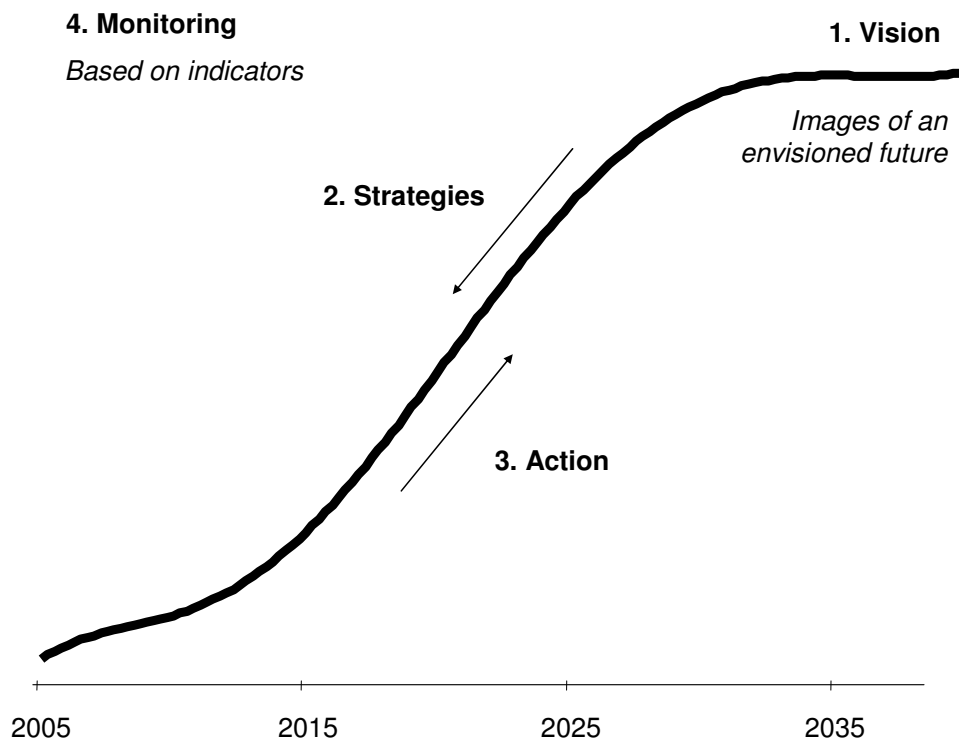


Figure 1.1. Sustainable development as a transition process (Source: based on Nevens et al., 2007)

1.2.2. Operationalisation of sustainability

Considering the transition framework visualised in Figure 1.1, another major asset of the monitoring tool is that it motivates and guides farmers to take effective actions towards more sustainable ways of agricultural production. Therefore, it is important that the monitoring tool is effectively used in practice on Flemish farms. To identify the necessary steps for making the monitoring tool an effective management tool, a validation process is required. This validation evaluates the tool's accuracy (Does the tool allow potential end-users to take effective actions?) and credibility (Are potential end-users actually willing to use the tool in practice?).

To make sustainability operational on Flemish farms, we develop and apply a procedure to validate the developed monitoring tool and we make suggestions for its effective application in practice.

1.3. Research outline

Considering the triple bottom line (people, planet, profit; Elkington, 1998) of sustainable development, three main dimensions of sustainability can be identified: ecological sustainability, economic sustainability and social sustainability. Sustainable development requires simultaneous and balanced progress in these three dimensions, that are totally interdependent. Aspects of these three dimensions were studied by Stedula (Steunpunt Duurzame Landbouw, the Flemish Policy Research Centre for Sustainable Agriculture, 2001-2006). This inter-university research group had the major task to make 'sustainable development' in Flemish agriculture concrete and apprehensible. In this thesis we focus on the ecological sustainability dimension. Aspects of economic and social sustainability of Flemish agriculture are discussed and summarized by Steunpunt Duurzame Landbouw (2006).

To achieve the main research objectives described above, we identified four phases in the research project (Figure 1.2):

1. designing indicators that make 'sustainability' concrete at the farm level and that enable to monitor the progress of Flemish farms towards sustainability;
2. aggregating the indicators into an integrated farm sustainability monitoring tool;
3. developing and applying a validation procedure for the indicators individually and for the monitoring tool as a whole;
4. making suggestions to improve the tool and its effective application in practice.

Figure 1.2 shows how the different chapters of this thesis fit into this strategy.

From an ecological viewpoint, three major topics of sustainable agriculture can be distinguished: (i) use of inputs, (ii) quality of natural resources and (iii) biodiversity. For each of them, we studied some individual aspects in more detail²: (i) use of energy and water, (ii) water quality and (iii) genetic and species diversity:

Chapter 2 focuses on biodiversity. We describe what defines biodiversity in relation to agriculture, we develop indicators for genetic diversity of agricultural crops and we present a methodology to develop indicators for species diversity.

² Other aspects of ecological, economic and social sustainability were worked out by Stedula, the results are summarized by Steunpunt Duurzame Landbouw (2006).

Indicators for energy use are the core of Chapter 3: we apply the indicators to evaluate the energy use of a representative set of specialised dairy, arable and pig farms in Flanders, we study the changes in time and we set achievable targets for energy use efficiency on Flemish farms.

Chapter 4 focuses on eco-efficiency, an important principle of ecological sustainable farming systems. We make eco-efficiency concrete for dairy farms in Flanders; we study the changes in eco-efficiency of a representative set of Flemish dairy farms between 1989 and 2001; and we describe some management aspects of dairy farms associated with high eco-efficiencies.

The developed methodologies for sustainability indicator design are described in Chapter 5. Here, we also report on the development of a farm sustainability monitoring tool, which integrates the ecological indicators, together with economic and social sustainability aspects.

In Chapter 6, we develop and apply a procedure to validate the integrated farm sustainability monitoring tool and the developed ecological indicators. Based on these validation results, we make suggestions concerning the design of the tool and its practical application. This chapter also describes the developed indicators for water use and water quality.

Chapter 7 is an executive summary, which clarifies the guiding principle throughout this work. Here, we summarize and discuss the main methodological aspects, research issues and conclusions and we make recommendations for an effective concretisation and operationalisation of sustainability on Flemish farms.

As all chapters are based on published articles the reader will find some inevitable repetitions and minor overlaps. The sequence of the chapters is logical at two levels:

- *Chapters 2, 3 and 4 deal with the study of individual aspects of ecological sustainability and focus on the development of indicators. Chapter 5 integrates the ecological indicators (together with economic and social sustainability indicators) and looks back on the general methodology of indicator development. In chapter 6, the work from the previous chapters is validated. Chapter 7 is an executive summary.*
- *All chapters except chapter 2 deal with sustainability issues at the farm level. For biodiversity, we found it primarily important to be able to evaluate the state and evolution of biodiversity at the regional level, considering the link between biodiversity at farm level and biodiversity at regional level. Therefore, in chapter 2 we focus on the development of biodiversity indicators at landscape level and this chapter comes first.*

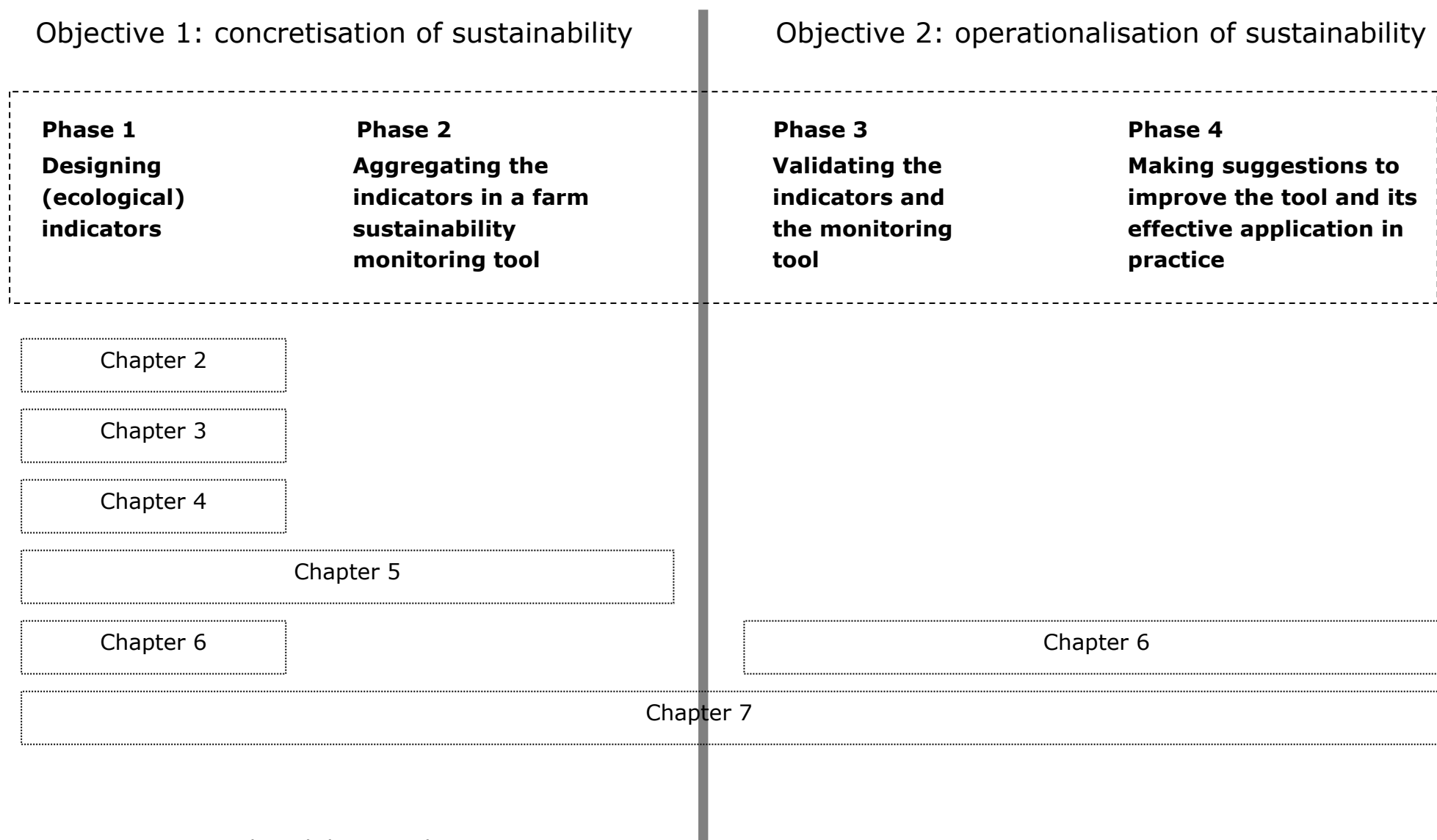


Figure 1.2. Research and thesis outline

Chapter 2

Indicators for biodiversity in Flemish agricultural landscapes



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Meul, M. 2007. A method to evaluate biodiversity in Flemish agricultural systems. Paper presented at the international symposium Farming Systems Design 2007, Catania, Italy, September 10-12.

Abstract

In this chapter, we developed indicators of changes in biodiversity related to agricultural landscapes in Flanders, using two case studies. In the first case study, we describe the evolution of crop diversity in Flanders, using three indicators to measure diversity between crops and within crops: the Shannon index, the evenness index – both used for diversity between and within crops – and genetic relatedness between varieties. Application of the indicators showed that despite an increase in the number of crops, the overall crop diversity in Flanders did not increase between 1950 and 2002. This was caused by the increasing dominance of a limited number of arable crops, maize in particular. The evolution of genetic diversity between varieties (within crops) from 1980 to 2002 was crop-specific: for maize, the indicators showed a decrease in genetic diversity, for potato and winter wheat an increase was found. In the second case study, we propose a statistically-based method to select indicator species for biodiversity within Flemish agricultural ecosystems and their natural environment. We considered the diversity of farmland birds as a case study. In the developed method, indicator species are selected based on the correlation between the presence of a species and a site's overall species richness. Population trends of selected farmland bird indicator species could be used to indicate changes in the diversity of farmland birds in Flanders and hence to indicate the quality of Flemish agricultural ecosystems. Moreover, for each indicator species, ecological knowledge relating to biotope quality, quantity and configuration can be used for region-specific management planning and/or evaluation.

Keywords: Agriculture, Biodiversity, Farmland birds, Flanders, Genetic diversity, Indicator

Indicators for biodiversity in Flemish agricultural landscapes

2.1. Introduction

2.1.1. Biodiversity and sustainable agriculture

In April 2002, the Parties of the Convention on Biological Diversity committed themselves “to achieve a significant reduction of the current rate of biodiversity loss by 2010, at the global, regional and national level; as a contribution to poverty alleviation and to the benefit of all life on earth” (CBD, 2007a). This objective was subsequently endorsed by the World Summit on Sustainable Development (Johannesburg, September 2002) and the United Nations General Assembly (UN, 2007a) and was incorporated in the Millennium Development Goals (UN, 2007b).

Protected areas are commonly recognized as important units for *in situ* biodiversity conservation (Chape et al., 2005; CBD, 2007a). Nevertheless, Dudley et al. (2005) argue that most of the world’s fauna and flora continues to exist outside these protected areas. Together with forests, agricultural landscapes play a key role in the conservation of biodiversity outside protected areas. More than any other economic sector, agriculture inherently makes use of biological resources and has a possible influence on biodiversity. Moreover, much of the biodiversity in Europe is found on, or adjacent to, farmland (Sepp et al., 2004). Conserving biodiversity in economically productive landscapes implies that biodiversity use is sustainable³ in the overall landscape. In addition, management should be compatible with the survival of some or all of the biodiversity originally present.

At the same time, agriculture has repeatedly been identified as one of the largest contributors to the loss of biodiversity world-wide (McLaughlin and Mineau, 1995). In recent years, agricultural expansion, combined with overgrazing and urban and industrial growth, has substantially reduced levels of biological

³ Article 2 of the CBD defines sustainable biodiversity use as: “the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations” (CBD, 2007b).

diversity over significant areas worldwide (CBD, 2007a). Current patterns of agricultural land use based on limited numbers of species and varieties have also diminished the biological diversity within agricultural ecosystems and are undermining the long-term sustainability of agricultural production itself (Altieri, 1999).

2.1.2. Agrobiodiversity

The Convention on Biological Diversity (Rio de Janeiro, 1992) defines biodiversity as 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part. This includes diversity within species, between species and of ecosystems' (CBD, 2007b).

Drawing on this definition, agricultural biological diversity, or agrobiodiversity is often considered in terms of three levels (OECD, 2001; Wascher, 2000):

- Genetic diversity (*within species*): the diversity of genes within domesticated plants and livestock species and their wild relatives;
- Species diversity (*between species*): the diversity of wild species (flora and fauna) affected by agriculture, including soil biota and the effects of non-native species on agriculture and biodiversity;
- Ecosystem diversity (*of ecosystems*): the diversity of ecosystems formed by populations of species relevant to agriculture or species communities dependent on agricultural habitats.

From a management perspective, Vandermeer and Perfecto (2005) recognize two distinct components of biodiversity in agricultural ecosystems (or agroecosystems):

- Planned biodiversity: the biodiversity associated with the crops and livestock purposely included in the agroecosystem and varying with the farmer's management (e.g. the use of inputs and crop spatial/temporal arrangements).
- Associated biodiversity: all fauna and flora colonizing the agroecosystem from the surrounding environments and thriving in the agroecosystem, depending on its specific management and structure (e.g. farmland birds).

Another classification of agrobiodiversity components is based on the role they play in the functioning of cropping systems (Swift and Anderson, 1993):

- Productive biota: crops, trees and animals chosen by farmers;
- Resource biota: organisms that contribute to productivity through pollination, biological control, decomposition, predation, etc.;
- Destructive biota: weeds, insect pests, microbial pathogens, etc. which farmers try to reduce or eliminate.

Management and functional classifications of agrobiodiversity might be useful to communicate with farmers about the influence of farm management on the different functions of biodiversity. However, these classifications are often complex and not always relevant for biodiversity itself. We therefore prefer to use the first mentioned definition of agrobiodiversity, comprising genetic diversity of domesticated plants and animals, species diversity of 'wild' fauna and flora and ecosystem diversity.

2.1.3. Biodiversity indicators

2.1.3.1. Indicators FOR or FROM biodiversity?

A major source of confusion on biodiversity indicators, lies in the mixed use of multiple terms such as 'biotic indicator', 'bioindicator' or 'biodiversity indicator' for multiple goals.

Until 1990, the term 'biotic indicator' or 'bioindicator' was used for a species or a group of species indicating environmental health or ecological processes such as disturbance, human impact and environmental change (Duelli and Obrist, 2003). After the Convention on Biological Diversity in 1992, there was a drastic shift in interest towards the search for indicators of biodiversity itself. In the latter interpretation of 'bioindicator', biodiversity itself is to be assessed, while in the first interpretation components of biodiversity are used as indicators for aspects outside biodiversity.

If a species or group of species is a good indicator for e.g. lead contamination (indicator FROM biodiversity), it may not indicate biodiversity itself (indicator FOR biodiversity). Thus, it is fundamentally a contamination indicator rather than a biodiversity indicator (Duelli and Obrist, 2003).

Some well-known examples of the use of fauna and flora as bioindicators (indicators FROM biodiversity) are:

- the Ellenberg Index (Ellenberg et al., 1991), which describes the response of individual species to a range of ecological conditions (light, temperature, continentality, moisture, pH and nitrogen). This indicator system was

established by Ellenberg for vascular plants of central Europe. The Ellenberg nitrogen (N) index allocates a score to plant species depending on the N content of the soil, so that the average community score indicates the nutrient richness of a specific site on a scale of nutrient poor to nutrient rich.

- the Index of Biotic Integrity (IBI; Karr, 1991), which evaluates the quality of aquatic biota by using a series of fish community attributes related to species composition and ecological structure. Belpaire et al. (2000) illustrated the applicability of this IBI for the assessment of ecological quality of Flemish water bodies.
- BBSK, a biological soil classification system based on the communities of several groups of soil organisms, which can be used as a reference for assessing biological soil quality (Ruf et al., 2003).

More examples of the use of indicators FROM biodiversity can be cited. In this chapter, however, we wish to focus on the search for indicators FOR biodiversity itself, which we will refer to as 'biodiversity indicators'.

2.1.3.2. Biodiversity indicators: two levels

A literature review on biodiversity indicators showed that indicators have to fulfil different requirements depending on the geographic level considered (e.g. field – farm – region – country) and on the goals that should be achieved. The establishment of a hierarchic system of indicators, including their linking-up considering the different levels and goals, is recommended (Büchs, 2003).

Considering the general objectives of this thesis as described in Chapter 1, biodiversity indicators at farm level should be able to evaluate and guide a farm in maintaining biodiversity and its sustainable use. These indicators should allow us to guide farmers towards more sustainable management practices related to biodiversity. For example, Altieri (1999) distinguished three main management-related characteristics that influence the degree of biodiversity in agroecosystems: (i) the diversity of vegetation within and around the agroecosystem, (ii) the permanence of a number of crops within the agroecosystem and (iii) the intensity of the management. An evaluation tool of management aspects that are related to these characteristics would allow us to evaluate a specific farm on its sustainable use of biodiversity and would provide farmers an insight into different measures for maintaining biodiversity.

However, a major concern in developing such an evaluation tool of management-related aspects, is to unfold the link between the management measures taken at the farm and their actual contribution to biodiversity at the regional level. Biodiversity is not limited to farm boundaries. Hence, we consider it primarily

important to be able to evaluate the state and evolution of biodiversity at the regional level, before effective management measures at farm level can be identified and evaluated. Therefore, the specific objective of this chapter was to develop indicators for agrobiodiversity at the (regional) level of Flemish agricultural landscapes. Considering the recommendations of Büchs (2003) mentioned above, these indicators should not blindly be applied at farm level. A farm evaluation tool for biodiversity should be developed that takes into account the link between management measures taken at farm level and their effect on biodiversity at the regional level.

2.1.3.3. Two case studies concerning the development of biodiversity indicators

According to Büchs (2003), it is nearly impossible to create basic rules or criteria for biodiversity indicators, due to the high diversity of goals these indicators often have to serve. Therefore, the definitions and basic demands that are related to an indicator have to be established case by case, each case requiring its own specific indicators.

In our search for agrobiodiversity indicators, we consider three cases: indicators for genetic diversity, indicators for species diversity and indicators for ecosystem diversity, according to the first classification of agrobiodiversity mentioned above (section 2.1.2).

In what follows, we describe two case studies. In the first, we developed indicators for genetic diversity of agricultural crops in Flanders. In the second, we constructed a methodology to select indicator species for biodiversity within Flemish agricultural ecosystems. These case studies cover the first two aspects of agrobiodiversity: genetic diversity of domesticated plants and animals and species diversity of 'wild' fauna and flora.

Ecosystem diversity is not considered in this work. However, according to Duelli and Obrist (2003), ecosystem diversity is somehow reflected in the species diversity (more specifically in the number of species present). More trophic levels will normally include more species and higher structural diversity will harbour more ecological niches. Moreover, although habitat condition can give an indication of the likelihood that certain species will be present, it offers little direct evidence of their actual presence, since specific pressures can reduce or eliminate some elements of biodiversity, even within a habitat that is apparently pristine (Dudley et al., 2005).

2.2. Indicators for genetic diversity of agricultural crops

2.2.1. Introduction

Diversity of agricultural crops enhances the stability and the sustainability of agro-ecosystems, since a high diversity between crops contributes to a higher diversity of associated wildlife species and habitats and hence to agrobiodiversity in general (OECD, 2001; Marshall et al., 2003). During the last few decades, the area planted with major crops has increased at the expense of the area of minor crops. For example, in Flanders maize exponentially became a major crop in the 1970s and its area has increased ever since, at the expense of some formerly important crops such as rye, barley, oat and fodder beet. Moreover, the rotation of crops has decreased, causing a general decrease in crop diversity. However, the growing concern to reduce pesticide application highlights the importance of diversity between and within crops, since genetic diversity offers opportunities to reduce the spread of diseases and pests and to slow down resistance development (Finckh et al., 2000).

Genetic erosion has significantly increased from the beginning of the 20th century, caused by the introduction of modern plant breeding (Vellvé, 1993; Clunies-Ross, 1995) and the development of new, mechanized production methods. Modern plant breeding resulted in uniform varieties, going hand in hand with uniform production techniques.

The breeding of our current, highly-performing crop varieties started from genetically diverse landraces and wild varieties. Continuous selection and breeding caused a shift in crop phenotype and genotype. On the one hand, breeding has led to an increase in genetic diversity, through the search for particular characteristics relating to growth habit, seed production, etc. On the other hand, selection and breeding have caused genetic erosion, since only the most suitable plants and varieties, often in terms of production, were selected (Wascher, 2000; OECD, 2001).

Bertin et al. (2001) found that with as little as ten original varieties, the genetic base of modern spelt (*Triticum spelta* L.) in Europe has become very narrow. Also, for chicory (*Cichorium intybus* L.) and sugar beet (*Beta vulgaris* L.), a great loss of genetic diversity in modern varieties has been shown (Bellamy et al., 1996; Desplanque et al., 1999; Van Stallen et al., 2000). For some other crops, however, it seems there has been no or only little genetic erosion. Donini et al. (2000) did not find any substantial decrease in genetic diversity in winter wheat (*Triticum aestivum* L.) varieties in the UK since 1930. Other studies concerning genetic diversity of wheat and barley (*Hordeum vulgare* L.) confirmed these results (Reeves et al., 1999; Manifesto et al., 2001; Christiansen et al., 2002).

Witcombe (1999) concluded that in regions where modern crop varieties are well established, plant breeding does not necessarily cause a loss of genetic diversity; in some cases even an increase of diversity within the cultivated gene pool is observed. However, in regions where mainly traditional varieties and landraces are grown, the introduction of modern varieties and modern plant breeding often does cause a loss of genetic diversity.

Today, it is common knowledge that genetic diversity within crops is of major importance as a unique and irreplaceable source for future plant breeding (FAO, 1996; Tripp and van der Heide, 1996; Collins and Hawtin, 1999; Dotlacil et al., 2001) that should allow agriculture to cope with new production methods, changing climatic conditions or changing consumer demands.

Therefore, it is important to monitor and follow up on the evolution of diversity between and within crops. In this study, we develop indicators for agricultural crop diversity in Flanders (Belgium) and we give an overview of the evolution during the last few decades. We consider diversity at two levels: diversity between crops and genetic diversity within crops (between varieties).

2.2.2. Materials and methods

2.2.2.1. Diversity between crops

To study all crops used in agricultural and horticultural production⁴ in Flanders, we relied on the data of the Belgian National Institute of Statistics (NIS, 1950–2002), which organizes a yearly survey on each farm in Belgium. All farmers are legally bound to respond to the questionnaire and thus to report which crops they grow on which area.

Using these data, we assessed the evolution of the overall crop diversity in Flanders by calculating the Shannon and evenness diversity indices for the years 1950, 1960, 1971, 1980, 1990, 2000 and 2002. Both indices simultaneously account for the number of crops and for their share in total agricultural area. The Shannon index (H ; Shannon and Weaver, 1949), a diversity index often used in ecology, is calculated as:

$$H = -\sum_{i=1}^N p_i \cdot \ln p_i$$

⁴ Meadows, pastures and fallow land were excluded from the analysis. The NIS data did not contain information on the different grass species and their relative areas.

where p_i is the share of crop i (= area of crop i /total agricultural area) and N is the total number of crops. Diversity (H) increases when the number of crops increases and/or when the crop area shares are more evenly distributed. The evenness index (E ; Pielou, 1966) is calculated as:

$$E = \frac{H}{H_{\max}} = \frac{H}{\ln N}$$

where $H_{\max} = \ln N$, the maximum Shannon index. E varies between 0 and 1, where E equals 1 when all crops have the same area; all crops are then equally important and diversity is high. The value of E is close to 0 when a limited number of crops take a major part of the agricultural area.

2.2.2.2. Diversity within crops

We assessed diversity within a crop by the above-mentioned Shannon and evenness indices, using the total specific crop area and the areas cropped with different varieties as data. In addition, we determined the relatedness between varieties, by calculating pairwise relationships, based on pedigree information. This pairwise relationship was quantified by the coefficient of parentage (CP). The CP between two individuals is the probability that two random gametes, one from each individual, carry alleles that are identical by descent (Falconer, 1981). The CP between two varieties P and Q is calculated as:

$$CP_{PQ} = \frac{1}{4} (CP_{AC} + CP_{AD} + CP_{BC} + CP_{BD})$$

where P 's parents are $(A \times B)$ and Q 's parents are $(C \times D)$ (Falconer, 1981). When P and Q have one common parent, while all other parents are mutually not related in any way, this will result in a $CP = 0.125$. Further, a $CP = 0.0625$ represents a cousin-cousin relationship between P and Q . When $CP = 0.03125$, P and Q are second cousins and when $CP = 0$, P and Q are not related in any way. When a specific crop has a high number of varieties with a high pairwise CP (≥ 0.125), relatedness between the varieties is high and we presume genetic diversity within this crop to be low.

We selected three crops to estimate within-crop diversity: maize, potato and winter wheat. Together, they represented 57% of total agricultural area (excl. meadows, pastures and fallow land) in Flanders in 2002. For each crop, we compared the situation in 2002 with the one in 1980.

2.2.3. Results and discussion

2.2.3.1. Diversity between crops

In 2002, NIS surveyed 101 crops in Flanders, compared to 67 crops in 1950. The values of the Shannon and evenness diversity indices increased between 1950 and 1971, subsequently decreased from 1971 to 1990 and became more or less stable from 1990 on (Figure 2.1). Overall, between 1950 and 2002, H decreased from 2.52 to 2.50 and E decreased from 0.58 to 0.53.

So, despite the increasing number of crops, there is no general increase in the diversity indices between 1950 and 2002. The reason is that the 'new' crops are mainly vegetables, which only have a small share in the agricultural area (Table 2.1). The evolution in the dominant arable crops therefore has a larger impact on the overall crop diversity.

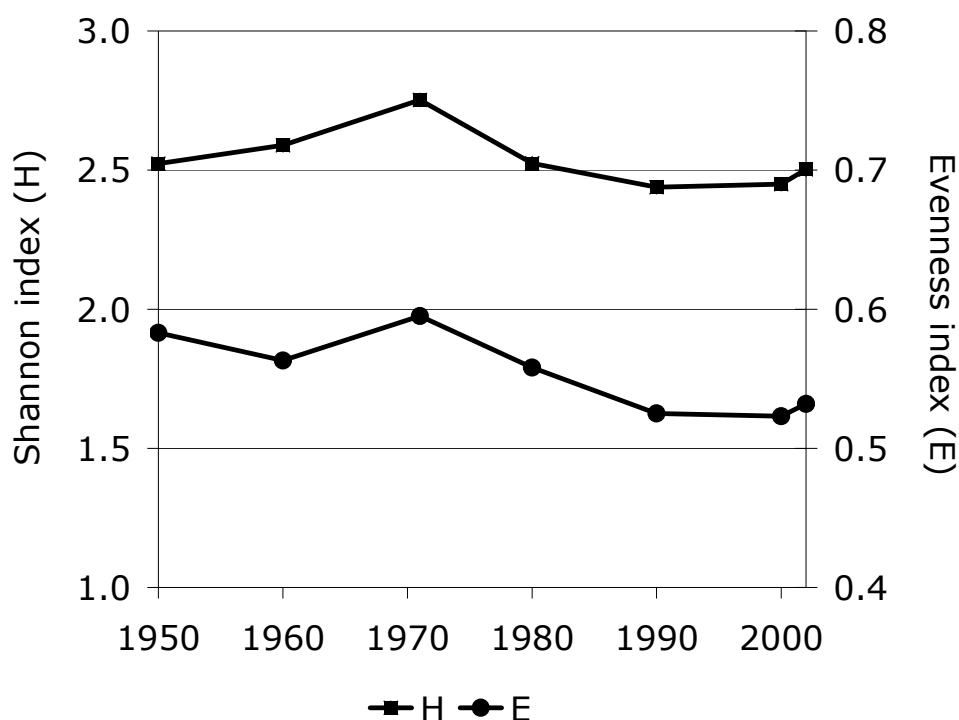


Figure 2.1. Shannon index and evenness index for crops in Flemish agriculture (1950-2002)

Table 2.1. The share (%) of arable crops and vegetables in the total agricultural area in Flanders (pastures, meadows and fallow land excluded)

	1950	1960	1971	1980	1990	2000	2002
Arable crops	92	91	90	92	90	88	91
Vegetables (outdoor)	1	1	3	3	4	4	4

Figure 2.2 shows the evolution of the diversity indices for both arable crops and vegetables. For vegetables, we observe an increase in both diversity indices, indicating an increase in diversity. For arable crops there was an increase in the indices between 1950 and 1971, but a sharp decrease between 1971 and 1990. To a large extent, the decrease can be explained by the substantial increase in the maize area, at the expense of a number of other crops.

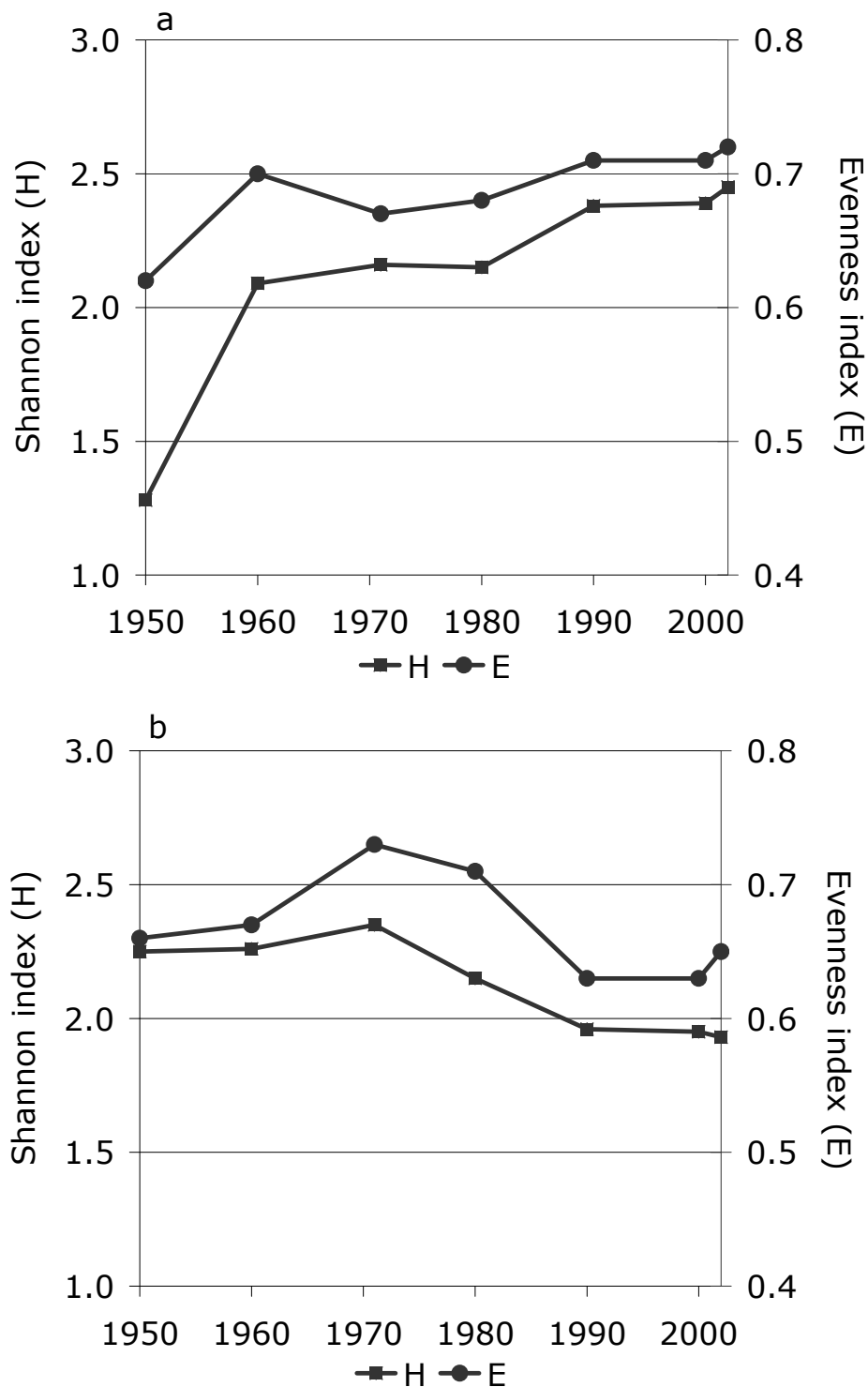


Figure 2.2. Shannon and evenness indices for vegetables (a) and arable crops (b) in Flanders between 1950 and 2002

2.2.3.2. Genetic diversity within crops

The values of the Shannon and evenness indices for potato and winter wheat increased between 1980 and 2002, indicating an increase in genetic diversity within the crops (Table 2.2). For maize, there were no reliable data available to calculate the indices in 1980. In 2002, the value of the indices (in particular H) is higher for maize, compared to potato and winter wheat. This is caused by a very high number of available maize varieties (287 varieties), compared to potato or winter wheat varieties (both 43 varieties).

From 1980 to 2002, the number of maize cultivars with a high CP (≥ 0.125) increased, from 1.8 to 7.5%. Recent maize varieties are often closely related, because seed companies cross top inbred lines with many other lines, thus creating a series of consanguineous varieties. For potato and winter wheat we observed a lower share of variety pairs with a high CP (≥ 0.125) in 2002, compared with 1980. This indicates an increase in genetic diversity between varieties of these crops.

Table 2.2. Shannon (H) and evenness (E) indices, and share of variety pairs within a specific coefficient of parentage (CP) range for maize, potato and winter wheat in 1980 and in 2002

	Maize		Potato		Winter wheat	
	1980	2002	1980	2002	1980	2002
H	- *	4.29	0.63	2.00	2.17	3.25
E	-	0.76	0.23	0.57	0.65	0.86
Share of pairs (%) with						
CP ≥ 0.125	1.8	7.5	7.3	3.7	6.9	6.0
0.125 > CP ≥ 0.0625	12.7	8.5	1.8	5.5	7.6	1.3
0.0625 > CP ≥ 0.03125	1.8	1.6	10.9	20.5	5.1	1.7
0.03125 > CP > 0	0	0	56.4	66.9	17.4	0.5
CP = 0	83.7	82.5	23.6	3.4	63.0	90.5

* - : no data available

2.2.3.3. Discussion

Indicators of genetic diversity of crops are used in some well-known international agri-environmental monitoring schemes, such as the agri-environmental indicators for sustainable agriculture in Europe, developed by the European Centre for Nature Conservation (ECNC; Wascher, 2000) or the environmental indicators for agriculture, developed by the Organisation for Economic Co-

operation and Development (OECD, 2001). Examples of such indicators are: the total number of crop varieties that are field grown or certified for marketing, the share of key crop varieties in total marketed production for individual crops, the change of the sum of all recognised crop varieties over time, or the number of national crop varieties that are endangered.

We consider the indicators we developed in the presented study more suited to evaluate the state and evolution of genetic diversity of crops in a specific region, for the following reasons:

- The indicators presented by ECNC and OECD do not consider the diversity of crop species, they focus only on the diversity of varieties. Yet, it has been shown that a high diversity between crops contributes to a higher diversity of associated wildlife species and habitats, as stated in the introduction part of this paper. Therefore it is important to consider this species diversity aspect.
- Indicators should be solid, which means that their calculation method should be well-documented, so that calculation is repeatable and the indicator value minimally depends on external factors (Meul et al., 2008; Chapter 5 of this thesis). The indicators that consider the share of key crop varieties and the number of varieties that are endangered do not meet this criterium. These indicators can be subject to personal interpretations of what is a 'key crop' and when it is 'endangered'. We therefore preferred to use indicators with a clearly defined calculation method such as the Shannon and evenness diversity indices and the coefficient of parentage.
- An increase in the number of varieties does not necessarily indicate an increase in diversity, as was shown by the example of diversity between crops in our study. When the 'new' varieties only have a small share in the agricultural area, they will not have a large contribution to the overall diversity. We therefore propose to simultaneously take into account the number as well as the share of each variety by using the Shannon diversity index.
- Moreover, the number of varieties does not take into account the genetic relatedness between the different varieties. Although in our study maize had by far the largest number of varieties, many of them were very closely related. Hence, this relatedness between varieties should also be considered.

The indicators presented in this study were approved and accepted by a feedback group of experts and stakeholders, who discussed the indicators' design, data use, calculation method and results (methodology described in more detail in Chapter 6 of this thesis).

We are aware that the computation of CP may have a relatively low absolute precision. Nevertheless, calculating CP averages and patterns may be useful for describing relative diversity in different regions or time periods (Cox et al., 1986; Murphy et al., 1986; Soleimani et al., 2002). Errors are mainly caused by incorrect assumptions (Witcombe, 1999). The pedigree information of some cultivars may be incorrect or incomplete. Also, the assumption is made that a cultivar derived from a cross between two parents will inherit half of its genetic material from each parent (Souza and Sorrells, 1989; Tinker et al., 1993), however, this is only fully true when the variety is a direct product of the cross between two parents, e.g. in single hybrids. Effects caused by mutation or selection are not taken into account.

Recently, evaluation of genetic diversity has shifted to the use of molecular markers, which are indicators of diversity at DNA level (Cox and Wood, 1999). Compared with pedigree analysis, DNA analysis may have a higher absolute precision for estimating genetic relatedness between varieties, but this precision is strongly dependent on the type and the number of markers that are used, their genome coverage and the crop studied (Messmer et al., 1993; Soleimani et al., 2002; Sun et al., 2003). Moreover, two cultivars may have the same allele of a particular marker simply by chance (i.e. they are identical "by state"), and not because they have inherited their alleles from a recent common parent (i.e. they are identical "by descent"). When a large enough array of markers is used, one can conclude that the genetic distance between two cultivars is indicated by the number of markers for which they carry contrasting alleles (Cox and Wood, 1999; Sun et al., 2003).

Correlation between relatedness measured either by CP or by molecular markers is often low (Schut et al., 1997; Sun et al., 2003); incongruities are the result of the inaccuracies of both methods. In this study we preferred pedigree data over DNA analysis, because calculation of CP is a quick, inexpensive and repeatable method that can essentially be applied by any person with basic knowledge of genetics. Moreover, within the frame of this thesis, we wish to develop indicators that allow us to translate sustainability into meaningful information and can guide actions. In our opinion, CP measures are more likely to reach these objectives than DNA analysis.

2.2.4. Conclusions

In the literature, the number of crops or varieties is often used as the sole indicator for genetic diversity between and within crops. Our study has shown that this indicator is not sufficient to assess genuine genetic diversity. By estimating crop diversity in Flanders using the Shannon and evenness indices, we indicated that, although the number of crops has increased since 1950, the

overall crop diversity did not follow, caused by the growing dominance of a limited number of arable crops. Genetic diversity within three crops was also assessed by the Shannon and evenness indices and additionally by the relatedness between varieties. Considering the period 1980–2002, the indicators showed an increase in diversity within potato and winter wheat, and based on CP, the diversity within maize decreased.

From this study, we are not able to make a sound conclusion on the actual 'state' of genetic diversity of crops in Flanders, since no reference base or benchmarks on genetic diversity exists (e.g. How much diversity is actually needed?). However, we did develop an instrument that can be used to describe the evolution over time of the genetic diversity of crops within a specific region. Considering its importance for sustainable agriculture and our research experience, we recommend that genetic diversity of crops is more closely monitored in the future and that it is taken into account when developing (new) sustainable agricultural production systems.

2.3. Indicators for species diversity

2.3.1. Introduction

Successful conservation and sustainable use of biodiversity requires, first of all, that species richness and composition of species assemblages in different habitats and in different taxa can be reliably assessed, often with limited resources available (a.o. Similä et al., 2006).

Several methods and indicators have recently been suggested for assessment of species diversity related to agriculture (e.g. Döring et al., 2003; Waldhardt et al., 2003; Hietala-Koivu et al., 2004; Fleishman et al., 2005). These biodiversity assessment tools often involve the use of indicator species. Very different interpretations of 'indicator species' can be found in literature (Godefroid and Koedam, 2003); in our study, we define indicator species as 'species with occurrence patterns that are correlated with the species richness of a larger group of organisms' (Fleishman et al., 2005). Stated differently, the presence of an indicator species is correlated with the presence of numerous other species (Godefroid and Koedam, 2003). If reliable indicator species can be assigned, it would be much easier to monitor their occurrence than to conduct comprehensive species inventories or habitat assessments to monitor overall biodiversity. From a management-oriented perspective, it is also easier to train field biologists and other personnel to identify a limited set of species and to design monitoring plans for a few indicator species than to expect this personnel to recognize and track an entire fauna or flora (Mac Nally and Fleishman, 2004).

Indicator species are often selected according to ad hoc criteria, such as their charisma, public acceptance, extent or legal protection status (Büchs, 2003; Mac Nally and Fleishman, 2004). Often a correlation between these indicator species and biodiversity is claimed, but remains untested. As argued by Godefroid and Koedam (2003) and Mac Nally and Fleishman (2004), a statistically based selection of potential indicators is better justified and likely to be more effective.

In this study, we adapt a statistically-based method, proposed by Godefroid and Koedem (2003), to select indicator species for biodiversity within Flemish agricultural ecosystems and their natural environment. As a case study, we develop indicator species for the diversity of farmland birds.

2.3.2. Materials and methods

2.3.2.1. Data sources

The presented method uses three distinct data sources, which we compiled into one data set to be used in the statistical analysis.

I. Map of Flemish ecoregions

Biodiversity varies dramatically with varying natural conditions and historic development of individual regions, landscapes and partial landscapes. Therefore, biodiversity assessment should take place under consideration of these regional differences and should be based on regionally adapted indicator species (Hoffmann and Greef, 2003; Buckland et al., 2005). Often the ecological needs of different (indicator) species are in conflict. For example, hedgerow breeder populations will be enhanced by planting and maintaining hedgerows, while the population density of open land birds will be reduced and vice versa. Hence different indicators potentially neutralise themselves in producing opposite results, particularly when used to indicate the success of certain measures applied. It does not seem sensible to use e.g. species typically associated with hedgerows as biodiversity indicators for the whole of Flanders.

Therefore, we consider a division of Flanders in 12 ecoregions (Figure 2.3). Thereby, an 'ecodistrict' is a spatial area that is considered homogeneous in the field of climatic, geological, geomorphologic, groundwater and surface water characteristics and soil type (Antrop et al., 2002). Ecodistricts are combined into 'ecoregions' based mainly on their similarity of geological and geomorphologic characteristics.

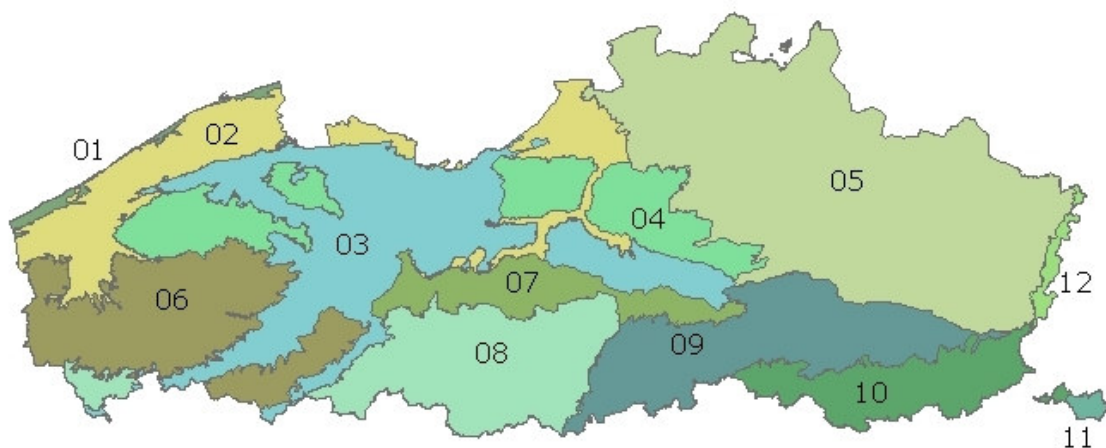


Figure 2.3. Map of Flemish ecoregions

II. Atlas of Flemish breeding birds

In 2000 a mapping scheme was started to compile an atlas of breeding birds in Flanders. This 'Atlas of Flemish breeding birds 2000-2002' was published in 2004 (Vermeersch et al., 2004). The large-scale monitoring project was financed by the Flemish government and was based on a co-operation between INBO (The Flemish Research Institute for Nature and Forest) and several organizations including regional and provincial councils, nature and youth organizations. Fieldwork was performed by volunteers and was carried out during the breeding seasons of 2000, 2001 and 2002. In general, fieldwork consisted of surveys on both 5x5km and 1x1km scales. In each 5x5km square (based on the Universal Transverse Mercator (UTM) projection to divide Flanders into an internationally recognized grid of 5x5km squares), volunteers were asked to locate as many breeding bird species as possible and to assess numbers as well as locations of a selected sub-set of species. Subsequently, as part of a standardized fieldwork procedure, two one-hour visits to sets of eight fixed 1x1km squares were made.

In the atlas, three different species maps are presented: a distribution map for each species where different colours represent the classification of breeding status (certain breeding, probable breeding or only possible breeding); a relative abundance map for each species that shows the level of certainty with which a species may be recorded at any location in Flanders; and finally, for some species a trend graph is presented.

We used the monitoring data of 3805 1x1km squares that were visited during the monitoring period of 2000-2002. For each square, a table shows the presence (1) or absence (0) of each species.

III. Agricultural land use map

The Flemish Land Agency yearly performs an inventory of all parcels under agricultural use, resulting in a digital map of agricultural land use in Flanders. For each parcel, the map contains information on the grown crops and manure legislation rules. These agricultural land use maps – together with other geographical information maps – are available on-line (<http://www.agiv.be/gis/>). We used the digital agricultural land use map of 2002.

IV. Compilation into one dataset

In a GIS (Geographical Information System) environment, we combined the three described information sources: we classified the 1x1km squares of Flemish breeding bird atlas according to the ecoregions and calculated the area under agricultural use for each square.

The result is a table that for each of the 3805 1x1km squares contains: (i) the ecoregion number, (ii) the presence or absence of each breeding bird species and (iii) the area under agricultural use. Based on this information, we calculated (iv) the total species richness as the total number of breeding bird species that were registered as 'present' and (v) the species richness of typical farmland birds. The latter parameter is based on the number of typical farmland bird species that were registered as 'present' in each square and it is essential to this study, since our aim is to identify indicator species for farmland bird diversity. From the extensive list of monitored breeding birds, experts of INBO identified 45 farmland bird species typically associated with agricultural landscapes in Flanders.

2.3.2.2. Selection of indicator species

The analysis started from the list of 45 farmland bird species typically associated with agricultural landscapes in Flanders. From this list, indicator species were selected based on the correlation between the presence of a species and a site's species richness (Godefroid and Koedam, 2003). Hereby, only species richness of typical farmland birds was considered.

The analysis was performed separately for each ecoregion and consisted of 3 successive steps:

Step 1: Statistical selection of indicator species

For each ecoregion, the 1x1km squares of the breeding bird atlas formed the basis of the analysis. Repeatedly, for each of the 45 farmland bird species, an independent t-test – or non-parametric Mann-Whitney-U test in case of less than 30 observations – was performed using SPSS statistical software: we compared the average species richness of the squares where the considered species was present with the average species richness of the squares where the considered species was absent. A species was selected as a significant indicator, when the average species richness of the squares containing the considered species was significantly higher. For each ecoregion, this analysis resulted in a list of significant indicator species for farmland bird diversity.

Step 2: Additional selection criteria

In a second step, we made an additional selection of indicator species, based on two criteria:

- Selection of intermediately rare species. Mac Nally and Fleishman (2004) argue that widespread species would not be useful for modelling variation in species richness and would thus have little potential to serve as indicators of species richness. Restricted species on the other hand occur at relatively few

sites and often have highly specific ecological requirements that are not shared with many other species. Therefore, we only retained species that were present in more than 20% and less than 80% of the considered 1x1km squares.

- Selection of species highly associated with agriculture. While all 45 farmland bird species are associated with agricultural landscapes, some of them more exclusively depend on agricultural habitats than others. Therefore, we only retained the indicator species for which the average utilised agricultural area of the squares containing the species was significantly higher.

Step 3: Final selection

As a final selection, per ecoregion, we limited the number of indicator species to three, by retaining the top-three indicator species in a ranking according to the highest farmland bird species richness.

2.3.3. Results and discussion

2.3.3.1. Selection of indicator species

To demonstrate the different steps of the proposed method for selecting indicator species, we give a detailed description of the results of the 'ecoregion of the Polders' (ecoregion 02, Figure 2.3), as an example.

Step 1: Statistical selection of indicator species

Ecoregion 02 encloses 337 1x1km squares, in which a total of 32 (out of 45) farmland bird species typically associated with Flemish agricultural landscapes were monitored. For each species, an independent t-test was used to test whether the average species richness of the squares containing the species was significantly higher. Table 2.3 shows the results of Barn Swallow (*Hirundo rustica*) as an example. The output shows that Barn Swallow was recorded in 261 1x1km squares. According to the t-test results, the average species richness of farmland birds (SR FB) was significantly higher ($p = 0.000$) for these squares, compared to the ones where Barn Swallow was absent. Hence, Barn Swallow was initially retained as a potential indicator species for species richness of farmland birds in ecoregion 02.

Step 2: Additional selection criteria

Barn Swallow was found present in 77% of all sampled 1x1km squares of ecoregion 02 and therefore complies with the criterion of intermediately rare species. Besides, the average agricultural area of the squares with Barn Swallow

was higher (77 ha) than the average agricultural area of the squares without the species (37 ha).

This analysis (step 1 + step 2) was repeated for the other 31 farmland bird species monitored in ecoregion 02. Nine indicator species were retained. They are summarized in Table 2.4.

Step 3: Final selection

Ultimately, the top-three indicator species ranked according to the highest farmland bird species richness were selected. As a result, for ecoregion 02, Black-tailed Godwit, Icterine Warbler and Oystercatcher are selected indicator species for farmland bird species richness (Table 2.4).

Table 2.3. Output of the independent samples t-test, comparing the average species richness of farmland birds (SR FB) and the average agricultural area (AA) of 1x1km squares when Barn Swallow is present or not (ecoregion 02, 337 1x1km squares)

Barn Swallow	N	Mean SR FB	Mean difference	t-test Sig.	Mean AA (ha)
Not present	76	13.47			37
Present	261	18.40	4.93	0.000	77

Table 2.4. Potential indicator species of farmland bird species richness in ecoregion 02. SR FB = species richness of farmland bird species, AA = agricultural area (ha), SR = species richness of all birds, (1) = in case the species is present, (0) = when the species is absent

Potential indicator species	Mean SR FB (1)	Mean SR FB (0)	Mean * difference	Presence (%)	Mean AA (1)	Mean AA (0)	Mean SR (1)	Mean SR (0)
Black-tailed Godwit (<i>Limosa limosa</i>)	20.79	16.37	4.42	21	75	66	35.60	30.79
Icterine Warbler (<i>Hippolais icterina</i>)	20.25	16.32	3.93	25	74	66	36.30	30.31
Oystercatcher (<i>Haematopus ostralegus</i>)	19.60	15.76	3.84	40	73	65	34.50	30.00
Tree Sparrow (<i>Passer montanus</i>)	19.58	15.99	3.59	36	80	61	34.63	30.18
Common Cuckoo (<i>Cuculus canorus</i>)	19.42	15.85	3.57	40	70	67	36.60	28.54
Common Kestrel (<i>Falco tinnunculus</i>)	19.00	16.24	2.76	38	75	64	33.75	30.59
White Wagtail (<i>Motacilla alba</i>)	19.00	15.20	3.80	55	72	63	33.77	29.38
Stock Dove (<i>Columba oenas</i>)	18.48	14.70	3.78	69	70	63	33.67	27.70
Barn Swallow (<i>Hirundo rustica</i>)	18.40	13.47	4.93	77	77	37	32.37	29.79

* Statistical significance of mean differences for all species : $p \leq 0.001$

2.3.3.2. Indicator species for all ecoregions

The analysis described in detail for ecoregion 02, was repeated for ecoregions 03 to 10 (ecoregions 01, 11 and 12 were too small to perform statistics). The final set of selected indicator species per ecoregion is summarized in Table 2.5.

Table 2.5. Selected indicator species for farmland bird diversity in different Flemish ecoregions

Ecoregion	Indicator species
02	Black-tailed Godwit (<i>Limosa limosa</i>), Icterine Warbler (<i>Hippolais icterina</i>), Oystercatcher (<i>Haematopus ostralegus</i>)
03	Patric (Perdix perdix), Skylark (<i>Alauda arvensis</i>), Yellow Wagtail (<i>Motacilla flava</i>)
04	Patric, Icterine Warbler, Skylark
05	Icterine Warbler, Oystercatcher, Stonechat (<i>Saxicola torquata</i>)
06	Patric, Meadow Pipit (<i>Anthus pratensis</i>), Whitethroat (<i>Sylvia communis</i>)
07	Skylark, Yellow Wagtail, Linnet (<i>Carduelis cannabina</i>)
08	Patric, Common Cuckoo (<i>Cuculus canorus</i>), Meadow Pipit
09	Yellow Wagtail, Tree Sparrow (<i>Passer montanus</i>), Common Kestrel (<i>Falco tinnunculus</i>)
10	Icterine Warbler, Common Cuckoo, Tree Sparrow

2.3.3.3. Discussion

I. Using indicator species

Population trends of the selected indicator species could be used to indicate changes in the diversity of farmland birds in Flanders and hence indicate the quality of Flemish agricultural ecosystems. According to the Atlas of Flemish Breeding Birds (Vermeersch et al., 2004), many common Flemish farmland birds show a rapid decline over the last three decades. These population trends can be combined into a composite index to indicate biodiversity changes; several methods are described by Buckland et al. (2005).

At European level, the trend in common farmland bird species is one of the environment-related indicators that highlight trends relevant to the EU's Sixth Environment Action Programme (6th EAP, European Commission, 2007a). The European Union has adopted this farmland bird index from the Pan-European

Common Bird Monitoring (PECBM) Project (EBCC, 2007), which uses common birds as indicators of the general state of nature using scientific data on changes in breeding populations across Europe. The latest report 'Trends of common birds in Europe, 2007 update' presents an enlarged set of population trends and indices of 124 common bird species in Europe between 1980 - 2005, based on data from 20 countries. All indicator species from Table 2.5 – except Oystercatcher – are monitored within PECBM.

Ecological knowledge relating to biotope quality, quantity and configuration of each indicator species can be used for region-specific management planning and/or evaluation (Brooks et al., 2004; Hilty and Merenlender, 2000). Dochy and Hens (2005) propose a number of site- and species-oriented protection measures for providing nesting, cover and (winter and summer) feed for Flemish farmland birds, both within the cropping system and its natural environment. Examples are: installing grass bufferstrips, beetlebanks, grain-edges or hedges, increasing the share of summer grains in the crop rotation, protecting nesting places, not using pesticides and fertilizers on field edges or using grass/clover mixtures.

II. Multi-species approach

Although indicator species may be effective within limited taxonomic boundaries, it is considered unlikely that indicator species from a single taxonomic group (e.g. birds) will provide information on the richness of an entire biota (all vertebrates, invertebrates and plants) at scales meaningful for most land-use decisions (Mac Nally and Fleishman, 2004). Inversely, it seems reasonable to assume that species richness of a given taxonomic group will be predicted more accurately on the basis of species drawn from that same taxonomic group than on the basis of species drawn from a different taxonomic group. Although Fleishman et al. (2005) have shown that individual and combined species richness of two taxonomic groups (birds and butterflies) could be explained using indicator species drawn either from both of those groups or exclusively from one of the groups.

Recent studies have shown fairly little evidence for co-variation of species richness between different taxa at either large or local scale (Similä et al., 2006). It therefore seems appropriate to apply a multispecies approach, as advocated by several authors (Maes and Van Dyck, 2005). The underlying rationale is that a carefully selected group of indicator species from different taxonomic groups allows a more integrative and representative assessment of biodiversity. Therefore, indicator species from other taxonomic groups (such as vascular plants, mammals, butterflies, amphibians and reptiles) should be selected and compiled together with the bird indicators into one set of indicator species for biodiversity in Flanders. Depending on the available data and monitoring scheme, the proposed method for selection of indicator species could also be applied to

the other taxonomic groups. However, for most taxonomic groups, this would require a species monitoring much more elaborate than is currently available in Flanders.

2.3.4. Conclusions

In this study, we proposed an objective, statistically based method to select indicator species for biodiversity within Flemish agricultural ecosystems and their natural environment. As a case study, we applied this method to select indicator species of farmland bird diversity.

Population trends of the selected indicator species could indicate changes in the diversity of farmland birds in Flanders. Additionally, ecological knowledge relating to biotope quality, quantity and configuration for each indicator species can be used for region-specific management planning and/or evaluation.

Considering that it is unlikely that indicator species from a single taxonomic group provide information on the richness of an entire biota, the selected list of indicator bird species should be extended with indicator species of other taxonomic groups, to cover multiple aspects of biodiversity.

Chapter 3

Indicators for energy use at Flemish farms



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Abstract

In this study, we determined the energy use and energy use efficiency of a representative set (Flemish Farm Accountancy Data Network, FADN) of specialised dairy, arable and pig farms in Flanders. Total energy use comprised direct energy, based on the consumed amounts of diesel, lubricants, electricity and other energy sources (e.g. natural gas); and indirect energy, consumed during the production of farm inputs such as mineral fertilisers, seeds, pesticides, concentrates, forages and field machinery. We studied the changes in energy use and energy use efficiency between 1989–1990 and 2000–2001 for dairy and arable farms and between 1989–1990 and 1997–1998 for pig farms. The results showed that the use of mineral fertilisers and animal feed accounted for a high share of the total energy use on the farms. Diesel use took the major part of direct energy use. For dairy and arable farms, total energy use per ha has decreased significantly over the considered time period; on pig farms, energy use per finishing pig equivalent (FPE) in 1997–1998 was comparable to that in 1989–1990. The most energy efficient dairy and pig farms were intensive farms, which combined a high production with a low energy use and which possessed a gross value added per production unit comparable to, or even higher than the average. Based on the energy productivity of the top 5% farms, target values were set of 35 l milk 100 MJ⁻¹ and 7.5 kg live weight 100 MJ⁻¹ for energy use on Flemish dairy and farrow-to-finish pig farms, respectively. On arable farms, the energy use efficiency was highly dependent on the grown crops. For that reason, it is recommended to calculate energy ratios at field level, for each separate crop.

Keywords: Arable farming; Dairy farming; Energy use efficiency; Flanders; Pig farming

Indicators for energy use at Flemish farms

3.1. Introduction

Efficient use of resources is one of the major assets of eco-efficient and sustainable production, also in agriculture. Eco-efficiency is a management approach that was acknowledged at the 1992 Rio Earth Summit as a way for companies and businesses to contribute to sustainable development (de Jonge, 2004). Eco-efficient production has been given many definitions, all of them however adding up to the one principle 'produce more from less'; adding maximum value with minimum use of resources and with minimum environmental impact (WBCSD, 2000; Jollands et al., 2004). In this study we focus on one aspect of eco-efficiency in agricultural production systems: energy use efficiency.

Inefficient energy use can result in severe environmental impacts. The emission of greenhouse gasses by combustion of fossil fuels contributes to climate change. As a consequence, the global mean temperature has increased during the past 100 years and raised concerns over global warming and uncertainty over future impacts on the climate (a.o. Pimentel et al., 1996). The reduction of greenhouse gas emissions requires a decreased use of fossil fuels. Partly this can be achieved by using more sustainable sources of 'green energy', such as wind, bio energy and solar energy; or by a substantial increase of the energy use efficiency (Corré et al., 2003), where the same amount of output is produced with less energy. The development of energy-efficient agricultural systems – with a low input of energy compared to the output of products – should therefore help to reduce agricultural emissions of greenhouse gasses (Dalgaard et al., 2001). To achieve this, knowledge about energy use in different agricultural systems is needed.

On farms, energy – whether fossil or renewable – is consumed in a 'direct' and an 'indirect' way (Hülsbergen et al., 2001; Pervanchon et al., 2002; Corré et al., 2003). Direct energy is used on the farm for agricultural activities, the use is directly measurable and it comprises mainly diesel fuel, electricity and natural gas. The energy that is used to produce farm inputs such as mineral fertilisers, seeds, pesticides, concentrates, forages and machines is indirect energy.

Energy use efficiency is often expressed by the 'energy price' (EP) of agricultural products (a.o. Refsgaard et al., 1998; Corré et al., 2003). This is the amount of energy (in MJ) needed for the production of one unit of product (e.g. 1 kg wheat,

1 l milk). The energy use involves all energy used directly and indirectly up to the moment that the products leave the farm ('farm gate approach'). In our study, we prefer to express energy use efficiency as the reverse of the EP (i.e. the amount of product produced with one unit of energy), since this better fits the above definition of eco-efficiency: produce more (output) from less (input).

In this paper we study energy use efficiency, comparing energy input to production output, of three major agricultural systems in Flanders. Our major aims are:

- to determine the total (direct + indirect) energy use of a representative set of specialised dairy, arable and pig farms in Flanders and calculate their energy use efficiencies;
- to study the changes in energy use and energy use efficiency at farm level between 1989 and 2001;
- to set achievable targets for energy use efficiency on farms in Flanders.

3.2. Materials and methods

3.2.1. Data and farm characteristics

The Flemish Farm Accountancy Data Network (FADN) is a database of technical and economic data from a representative set of Flemish farms. From this dataset we used the data of the specialised dairy and arable farms in 1989, 1990, 2000 and 2001. For the specialised pig farms, we used the data of 1989, 1990, 1997 and 1998; data of 2000 and 2001 were considered unreliable, due to a food safety hazard in the sector in Flanders (dioxin in the production chain).

We considered farms as 'specialised' when at least 95% of the farm income originated from dairy activity. On specialised arable farms and specialised pig farms, at least 66% of the standard gross margin (SGM) originated from arable or pig production, respectively; SGM being the average monetary value of gross production minus specific costs for a given region (Commission of the European Communities, 1985). A selection of average characteristics of the farms is presented in Table 3.1.

3.2.2. System boundaries

Jones (1989) presented a hierarchy of methods for energy use analysis in agro-ecosystems, based on the applied system boundaries. The method used in our study corresponds to 'process analysis', where all energy inputs (direct and

indirect) to an agricultural system are considered, based on physical material flows. Human labour and solar energy are not considered in this method. We only included the indirect energy use one step backwards from the farm. This means that we included e.g. the energy used to produce fertilisers, but not the energy used to manufacture the equipment to produce the fertilisers. According to Refsgaard et al. (1998), by applying these boundaries, over 90% of the energy input in the whole production process of farm inputs is covered. We considered the energy used up to the point where the products leave the farm ('farm gate approach', Corré et al., 2003), which means that the energy required for packing, drying, storing and transporting products from the farm to consumers was not taken into account. Our system limits are supported by the fact that our major aim is to evaluate farm energy use, not to make a complete life cycle analysis of a product.

Table 3.1. Average characteristics of the specialised dairy, arable and pig farms in the dataset extracted from the Flemish Farm Accountancy Data Network

	Unit	1989	1990	2000	2001
<i>Dairy farms</i>	#	169	165	78	69
Utilised area	ha	28	28	32	32
Stocking rate	cows ha ⁻¹	1.73	1.73	1.64	1.62
Milk production	l cow ⁻¹ year ⁻¹	5319	5365	6017	5827
	l ha ⁻¹ year ⁻¹	9607	9567	10043	9643
<i>Arable farms</i>	#	64	57	55	50
Cultivated area ^(a)	ha	50	52	63	65
Number of crops		7	7	7	7
		1989	1990	1997	1998
<i>Pig farms</i>	#	85	98	97	98
Number of pigs	FPE ^(b)	675	792	1207	1249

^(a) The cultivated area is the sum of the areas of all cultivated crops during 1 year. Since a parcel of land can be used to grow more than one crop during one year, this area can be larger than the utilised area.

^(b) FPE = Finishing pig equivalent: 1 finishing pig = 1 young sow = 1 FPE; 1 sow = 2 FPE; 1 boar = 1.5 FPE.

3.2.3. Energy input parameters

For each year considered, we calculated the total of direct and indirect energy input (MJ) of a farm. Thereby, we considered direct energy input as the energy used on the farm for field and livestock operations, comprising diesel fuel (including contract work diesel), lubricants, electricity and other energy carriers

(e.g. natural gas). The accounted energy included the caloric energy content (this is the amount of energy released when the fuel is combusted) and the energy used for mining, transformation and transport of the energy carrier.

According to our above defined system boundary, indirect energy input to the farm included the energy needed for the production of mineral fertilisers, seeds, pesticides, concentrates, forages and field machinery. For indirect energy inputs, the accounted energy included the energy for their manufacturing, processing and transporting.

Total direct and indirect energy inputs on a farm were calculated on an annual base. We multiplied the consumed amounts of inputs – extracted from the FADN – by their corresponding energetic values. All energetic values used in our study were based on scientific literature, they are summarized together with the data entries from the FADN in Table 3.2.

3.2.4. Output parameters

We used the total annual milk production as the output parameter for the specialised dairy farms. We did not consider the amount of produced meat as an output parameter; firstly because the main purpose of a dairy farm is to produce milk and secondly because meat production on the studied specialised dairy farms is small (since 95% of the farm income originates from dairy activities). Therefore, we allocated the energy input only to milk production.

For the pig farms we distinguished between piglet-production farms (specialised in piglet production) and farrow-to-finish farms that breed and raise pigs to their slaughter weight. For the piglet-production farms, the total annual weight of produced piglets was used as the output parameter. For the farrow-to-finish farms, we used the total annual live weight of produced finishing pigs. Those output parameters could be extracted directly from the FADN.

For arable farms, we calculated the total amount of produced energy, by multiplying the crop yields (extracted from FADN) with the respective energy content of the crops (Table 3.3). We used crop energy output instead of produced crop amounts, since this enables us to account for the various crops in a common unit.

Table 3.2. FADN entries and energetic values used to calculate the different production inputs

Input	FADN entries		Energetic values		
	Data	Unit	Value	Unit	Reference ^(a)
Direct energy					
Diesel	amount of diesel	l	40.68	MJ l ⁻¹	a,b,c,d,e,f,g
Lubricants	amount of diesel	l	3.6	MJ l ⁻¹ diesel ^(b)	a
Electricity	amount of electricity	kWh	5.65 ^(c)	MJ kWh ⁻¹	d,e,h,i
Other sources ^(d)	amount of energy	MJ			
Indirect energy					
Field crops					
Seeds ^(e)					
Winterwheat	cultivated area	ha	571	MJ ha ⁻¹	c,j,k
Sugarbeet	cultivated area	ha	419	MJ ha ⁻¹	c,l,m
Potato	cultivated area	ha	1300	MJ ha ⁻¹	c,n
Maize	cultivated area	ha	168	MJ ha ⁻¹	b,o
Grass	cultivated area	ha	132	MJ ha ⁻¹	b,k
Mineral fertilizer					
N	amount of N	kg	55.3	MJ kg ⁻¹	a,b,c,p,q
P ₂ O ₅	amount of P ₂ O ₅	kg	15.8	MJ kg ⁻¹	c
K ₂ O	amount of K ₂ O	kg	9.3	MJ kg ⁻¹	c
Pesticides					
Fungicides	amount of AI ^(f)	kg	276	MJ kg ⁻¹ AI	a,b,c
Herbicides	amount of AI	kg	214	MJ kg ⁻¹ AI	a,c,p
Insecticides	amount of AI	kg	278	MJ kg ⁻¹ AI	a,c
Machinery	amount of diesel	l	12	MJ l ⁻¹ diesel ^(b)	a
Animal production					
Dairy cows					
Concentrates	purchased amount	kg	6.3	MJ kg ⁻¹	o
Maize silage	purchased amount	kg	2.2	MJ kg ⁻¹ DM ^(g)	b,o
Grass silage	purchased amount	kg	1.5	MJ kg ⁻¹ DM	o
Pig production					
Piglets feed	purchased amount	kg	6	MJ kg ⁻¹	r
Pig feed	purchased amount	kg	3.4	MJ kg ⁻¹	r
Sow feed	purchased amount	kg	3.7	MJ kg ⁻¹	r

^(a) a: Dalgaard et al. (2001); b: Wells (2001); c: Hülsbergen et al. (2001); d: Maertens and Van Lierde (2003); e: Vito (2004); f: Australian Institute of Energy (2004); g: Boustead (2003); h: EMA (2002); i: FPS Economy (2004); j: Refsgaard et al. (1998); k: Dekkers (2002); l: Ministry of Agriculture (2001); m: Bonneze (Iscal Sugar nv., pers. comm.); n: PCA (Interprovinciaal Proefcentrum voor de Aardappelteelt, pers. comm.); o: de Haan and Feikema (2001); p: Gezer et al. (2003); q: Gliessman (2000), r: van der Werf et al. (2005). In case of multiple references, average values were used.

^(b) The energy input from lubricants and the energy needed for production of field machinery is related to the amount of diesel used during field operations.

^(c) This value takes into account the share of electricity from nuclear energy and fossil fuels. All necessary data were found in the cited references.

^(d) Other sources: direct energy use from energy carriers other than diesel and electricity; not further specified in FADN.

^(e) We accounted the energy required to produce the amount of seed necessary for the production of 1 ha of the crop.

^(f) Active ingredient.

^(g) Dry matter.

Table 3.3. Energy contents of the most important arable crops in Flanders

Crop ^(a)	Energy content MJ kg ⁻¹ fresh product	Moisture content (%)	References ^(b)
Winter wheat	15.5	9.6	a,b,c,d
Winter rye	14.0	11.0	c
Winter barley	15.8	10.0	b,c,d
Oat	16.3	8.2	c,d
Maize (grain)	15.3	10.4	c
Maize (silage)	5.5	68.0	a
Sugar beet	5.3	77.0	a,b
Potato	3.4	77.0	b,c
Crop seeds	16.4	10.0	d
Vegetables	1.3	90.0	c
Fruits	2.0	85.0	c

^(a) Sugar beet and potato: without leaves. For cereals, only the grain is considered: straw is not used as an energy-source, it is therefore seen as a by-product.

^(b) a: NOVEM (1992); b: Hülshbergen et al. (2001); c: USDA (2004); d: Moerschner and Lücke (2002). In case of multiple references, average values were used.

3.2.5. Energy use efficiency

We expressed the energy use efficiency by the amount of product produced with one unit of energy, according to the definition of eco-efficiency: produce more (output) from less (input). For dairy farms and pig farms we therefore calculated the ratio between the amount of product (litre milk, kilogram live weight) and the total energy input, which we define as 'energy productivity'. For arable farms we calculated the ratio of total energy output and total energy input – 'energy ratio' – which expresses the total amount of crop energy that is produced per

unit of energy input. All calculations were made on farm level and on an annual basis.

We studied the changes in energy use efficiency between 1989 and 2001 on dairy and arable farms. For the FADN pig farms, energy productivity was only calculated for 1997–1998, since production results of 1989–1990 were not available.

3.2.6. Target values

For each farm type, we compared the average farm and management characteristics of the 5% most energy efficient farms from our dataset with those of all farms. We further used the energy use efficiency performances of those top performing 5% farms to establish achievable targets for energy use on farms in Flanders.

3.3. Results and discussion

3.3.1. Energy input

Table 3.4 shows the average energy inputs on the specialised dairy, arable and pig farms from our dataset. These results illustrate the importance of indirect energy input: it comprised about 70% of the total energy use on dairy and pig farms; on arable farms this was little more than 50%. Particularly the use of mineral fertilisers and animal feed accounted for a high share of the total farm energy use. On dairy farms, almost 60% of total energy input in 2000–2001 could be attributed to the used mineral fertilisers and concentrates. On arable farms, the production of mineral fertilisers consumed 34% of total energy input and the production of pig feed accounted for 68% of total energy use on pig farms. Diesel use took the major part of direct energy use and accounted for about 23% of total energy use on dairy and pig farms, and for 38% of total energy use on arable farms.

For dairy and arable farms, total energy use per ha has decreased significantly over the considered time period (-19% on dairy farms and -8% on arable farms). This decrease mainly originated from a lower use of mineral fertilisers and concentrates (Table 3.4). On pig farms, the energy use per finishing pig equivalent (FPE) in 1997–1998 was comparable to that in 1989–1990.

Table 3.4. Annual average energy input on specialised dairy, arable and pig farms in Flanders

	<u>Dairy farms</u>				<u>Arable farms</u>				<u>Pig farms</u>			
	1989-1990		2000-2001		1989-1990		2000-2001		1989-1990		1997-1998	
	MJ/ha	%	MJ/ha	%	MJ/ha	%	MJ/ha	%	MJ/FPE ^(a)	%	MJ/FPE	%
Direct energy input												
Diesel	7422	16.5	8044	22.1	7983	35.2	7899	37.7	709	19.9	810	22.8
Lubricants	524	1.2	534	1.5	571	2.5	508	2.4	5	0.1	7	0.2
Electricity	4345	9.6	3458	9.5	1063	4.7	1091	5.2	227	6.4	198	5.6
Other sources	149	0.3	109	0.3	341	1.5	519	2.5	36	1.0	25	0.7
<i>Total</i>	<i>12439</i>	<i>27.6</i>	<i>12144</i>	<i>33.4</i>	<i>9958</i>	<i>43.9</i>	<i>10017</i>	<i>47.8</i>	<i>977</i>	<i>27.4</i>	<i>1040</i>	<i>29.2</i>
Indirect energy input												
Mineral fertiliser	14549	32.3	8364	23.0	9171	40.4	7109	33.9	63	1.8	51	1.4
Seeds	165	0.4	163	0.4	477	2.1	470	2.2	5	0.1	5	0.1
Pesticides	189	0.4	220	0.6	1047	4.6	1490	7.1	7	0.2	8	0.2
Machinery	2228	4.9	2424	6.7	2030	8.9	1873	8.9	24	0.7	23	0.7
Cow feed:												
Concentrates	15182	33.7	12897	35.5								
Forages	302	0.7	161	0.4								
Pig feed									2492	69.9	2430	68.3
<i>Total</i>	<i>32616</i>	<i>72.4</i>	<i>24228</i>	<i>66.6</i>	<i>12724</i>	<i>56.1</i>	<i>10942</i>	<i>52.2</i>	<i>2590</i>	<i>72.6</i>	<i>2517</i>	<i>70.8</i>
Total energy input	45055	100	36372	100	22683	100	20959	100	3567	100	3557	100

^(a)FPE = Finishing Pig Equivalent

3.3.2. Energy use efficiency

3.3.2.1. Dairy farms

Figure 3.1 shows the total energy input per ha in relation to the production intensity (litre milk per hectare) of dairy farms. In 1989–1990, 90% of the set of specialised dairy farms operated between energy productivity isoquants of 14.5 and 30.0 l milk 100 MJ⁻¹, the average was 21.6 l milk 100 MJ⁻¹. In 2000–2001, 90% of the dairy farms operated at 16.7–39.0 l milk 100 MJ⁻¹, with an average of 27.1 l milk 100 MJ⁻¹. This corresponds with an increase in energy productivity of 25% between 1989 and 2001. Considering the decreased total energy use (Table 3.4), the studied dairy farms succeeded in keeping up or increasing their milk production with a substantially lower energy use, mainly originating from a lower use of mineral fertilisers and concentrates. Aspects of operational management that are potentially effective for decreasing the use of mineral fertilisers and concentrates might be found in measures such as crop rotation and ley/arable rotation, ration optimization and increased forage milk production, incorporation of clover-based swards or improved manure management and manure quality (Nevens et al., 2006). The actual management measures leading to the observed increased energy productivity could not be derived from the FADN data.

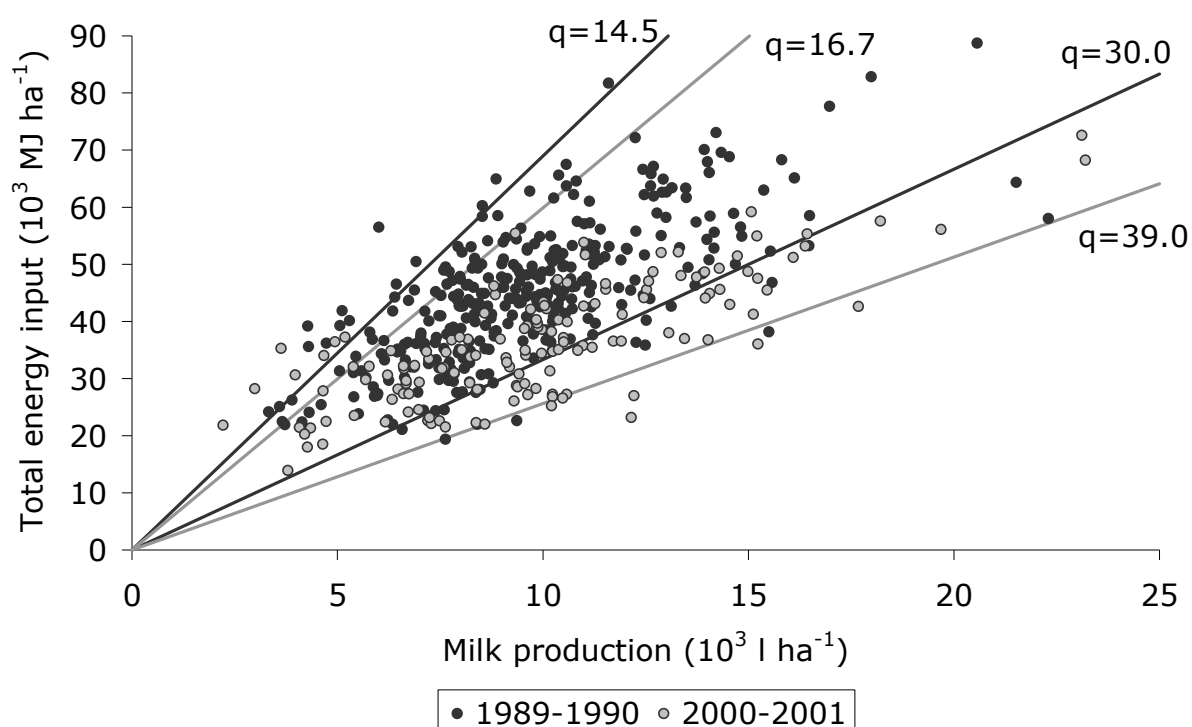


Figure 3.1. Energy input in relation to produced milk: data of Flemish specialised dairy farms in 1989–1990 and 2000–2001. Lines are isoquants of energy productivity: q = energy productivity (l milk 100 MJ⁻¹)

The observed energy productivities in our study are consistent with values from literature: 15.4 l milk 100 MJ⁻¹ (Hageman and Mandersloot, 1994), 13 to 26 l milk 100 MJ⁻¹ (Hageman, 1994), 23 to 32 l milk 100 MJ⁻¹ (Halberg, 1999) and 30 l milk 100 MJ⁻¹ (Koskamp et al., 2000).

Table 3.5 shows that the total energy input of a group of 24 best performing dairy farms (the 5% most energy efficient farms from our dataset) was only 73.5% of the average energy input of the total dairy farm set. The lower energy input on these farms originated mainly from a lower use of mineral fertilisers (-38%) and concentrates (-31%). The lower input of mineral fertilisers can not be attributed to more optimal weather conditions or inherent soil fertility (influencing crop and forage yields), since the group of 24 best performing farms, as well as the group of lowest performing farms (with lowest energy efficiency – not mentioned in Table 3.5) both contained farm data from all years (1989, 1990, 2000 and 2001) and from all agricultural regions in Flanders. The lower input of concentrates could be attributed to the fact that the top performers 'outsource' a less energy efficient part of the production (breeding heifers), as can be seen from Table 3.5 (share of dairy cows is 26% higher on the top performing farms).

Despite the lower use of inputs, milk production per ha was 25% higher on the best performing group, compared to the average for all dairy farms. This was achieved by a higher milk production per cow (+8%) and a higher stocking rate (+14%). This shows that the most energy efficient farms were not necessarily the most extensive ones, on the contrary, they were characterised by highly productive cows and a high stocking rate.

The trendsetting farms showed an average gross value added per litre milk that was 18% higher and a N use efficiency that was even 59% higher compared to the average of the total dairy farm set (Table 3.5). The N use efficiency was hereby defined as the ratio between the farm's product outputs (litres of produced milk) and the farm-gate N surplus (=N input - N output) (Meul et al., 2005).

Those results show that energy efficiency on farms can be optimised through management practices. Hereby, an energy efficient management has positive trade-offs on the N use efficiency and can be combined with good economic results. The latter was also found for N use efficiency on specialised dairy farms in Flanders (Nevens et al., 2006).

Based on the energy productivity results of the best performing dairy farms, a target value of 35 l milk 100 MJ⁻¹ can be realised in practice, at production levels of 12,000 l ha⁻¹ or higher.

Table 3.5. Average characteristics of the specialised dairy farms in the FADN and of a subgroup of 24 top performing farms with regard to energy productivity (data of 1989, 1990, 2000 and 2001)

Topic	Top performing farms	All farms	Top performing farms compared to all	
	n = 24	n = 483	Absolute	Relative (%)
Utilised area (UA) (ha)	28.9	29.1	-0.2	99.3
Share of grassland in UA (%)	69.0	68.4	0.6	100.9
Stocking rate (cows ha ⁻¹)	1.9	1.7	0.2	113.5
Share of dairy cows (%)	64.9	51.3	13.6	126.5
Energy input (MJ ha ⁻¹)				
Diesel	6489	7612	-1123	85.2
Lubricants	399	527	-128	75.7
Electricity	3605	4074	-469	88.5
Other sources	53	137	-84	38.7
Mineral fertiliser	7896	12659	-4763	62.4
Seeds	135	164	-29	82.3
Pesticides	189	199	-10	95.0
Machines	1965	2288	-323	85.9
Concentrates	9955	14484	-4529	68.7
Forages	496	259	237	191.5
<i>Total</i>	<i>31182</i>	<i>42402</i>	<i>-11220</i>	<i>73.5</i>
Milk production (l ha ⁻¹)	12104	9669	2435	125.2
(l cow ⁻¹)	5986	5521	465	108.4
Energy productivity (l 100MJ ⁻¹)	38.8	22.8	16.0	170.2
N use efficiency (l kg ⁻¹ N surplus)	48.9	30.7	18.2	159.3
Gross value added (€ 100l ⁻¹)	26.35	22.28	4.07	118.3

3.3.2.2. Pig farms

Figure 3.2 shows the relationship between total energy input at farm level and the weight of produced piglets (for piglet-production farms) or the live weight of produced pigs (for farrow-to-finish farms). The piglet-production farms showed an average energy productivity of 2.8 kg piglets 100 MJ⁻¹. The farrow-to-finish farms had an average energy productivity of 5.9 kg live weight 100 MJ⁻¹,

comparable with values of 5–10 kg live weight 100 MJ^{-1} found by Halberg (1999) on Danish pig farms. The average energy productivity of three FADN specialised finishing farms was $10.9 \text{ kg live weight } 100 \text{ MJ}^{-1}$. These results suggest that piglet production should not be compared to the production of finishing herds, since the latter is more energy efficient (of course piglets are necessary to establish finishing herds).

Since the FADN only contained information on 3 specialised finishing farms and 21 piglet-production farms, we could not make a sound analysis of the farm characteristics to explain the variations in energy productivity. For the farrow-to-finish farms, we compared the characteristics of the 5% most energy efficient farms with the average characteristics of all farms (Table 3.6). The average total energy input per FPE on the top performing farms was 23% lower than the average. Mainly diesel (-52%) and feed use (-16%) were substantially lower. On the other hand, the total produced live weight per FPE was 12% higher on the top performing group, which resulted in a 45% higher energy productivity. The gross value added per kg live weight on the top 5% of the farms was the same as the average of all farrow-to-finish farms.

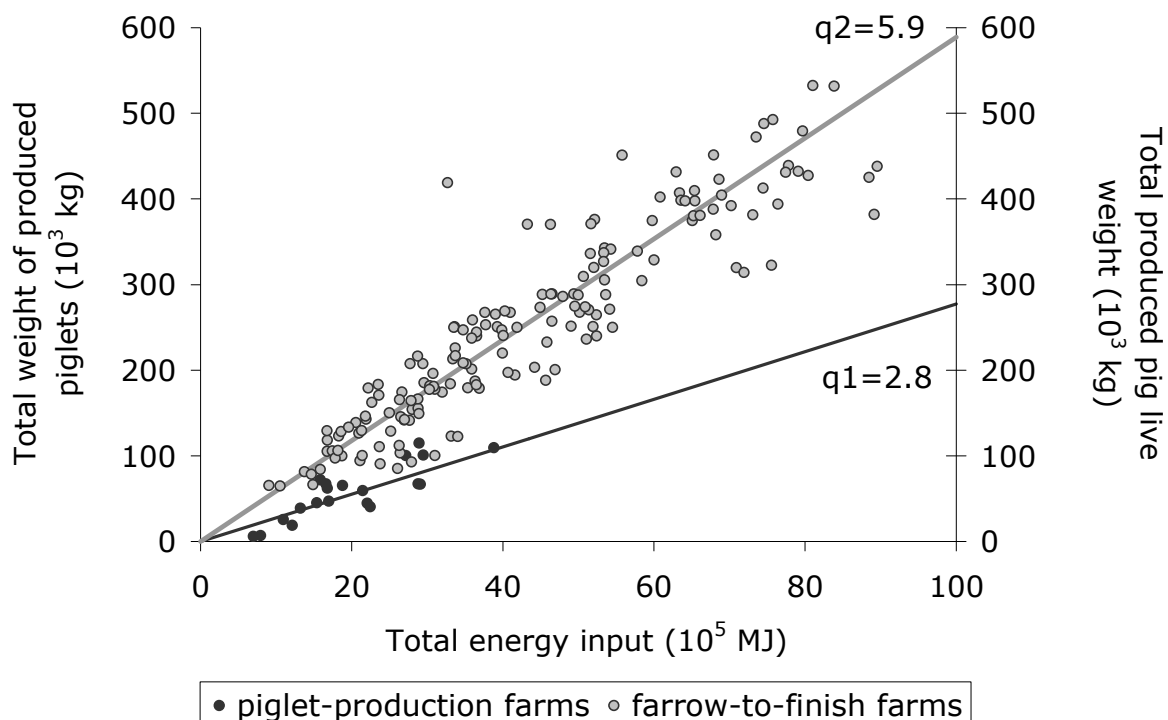


Figure 3.2. Energy input in relation to produced outputs: data of Flemish specialised pig farms in 1997–1998. Lines are isoquants of energy productivity: q_1 = energy productivity of piglet-production farms ($\text{kg piglets } 100 \text{ MJ}^{-1}$); q_2 = energy productivity of farrow-to-finish farms ($\text{kg live weight } 100 \text{ MJ}^{-1}$)

Based on the results of the best performing farrow-to-finish farms, a production of $7.5 \text{ kg live weight } 100 \text{ MJ}^{-1}$ is an achievable target value.

Table 3.6. Average characteristics of the farrow-to-finish farms in the FADN and of a subgroup of 9 top performing farms with regard to energy productivity (data of 1997 and 1998)

Topic	Top performing farms	All farms	Top performing farms compared to all	
	n = 9	n = 170	Absolute	Relative (%)
Number of pigs (FPE ^(a))	1562	1332	230	117.3
Energy input (MJ FPE ⁻¹)				
Diesel	318	669	-351	47.6
Lubricants	3	6	-3	46.9
Electricity	180	193	-13	93.3
Other sources	8	19	-11	41.5
Mineral fertiliser	75	61	14	122.6
Seeds	2	6	-4	34.1
Pesticides	5	9	-3	62.8
Machines	13	25	-12	50.8
Feed	2048	2444	-396	83.8
<i>Total</i>	2652	3432	-780	77.3
Produced live weight (kg FPE ⁻¹)	223	199	24	112.0
Energy productivity (kg 100MJ ⁻¹)	8.4	5.8	2.6	144.9
Gross value added (€ kg ⁻¹)	0.3	0.3	0.0	100.0

^(a)FPE = Finishing Pig Equivalent

3.3.2.3. Arable farms

Figure 3.3 shows the large variation in the energy ratios of the specialised arable farms. In 1989–1990, the average energy ratio was 5.5 and 90% of the farms obtained an energy output between 2.3 and 8.7 MJ MJ⁻¹ of energy input. In 2000–2001, 90% of the farms operated between energy ratio isoquants of 1.4 and 10.3, with an average of 5.9. Contrary to the dairy farms, there was no clear shift in energy use efficiency from 1989–1990 to 2000–2001. A change in the applied crop rotations and the relatively low decrease in applied mineral fertiliser (Table 3.4) could explain this difference. On arable farms, there is less need to reduce the amount of mineral fertilisers, since they have less difficulty being manure legislation compliant.

Depending on the crop rotation, production method and fertilisation rate, energy ratios between 0.7 and 16.2 were reported in other studies concerning energy use efficiency on arable farms (Hülsbergen et al., 2001; Helander and Delin, 2004; Ozkan et al., 2004).

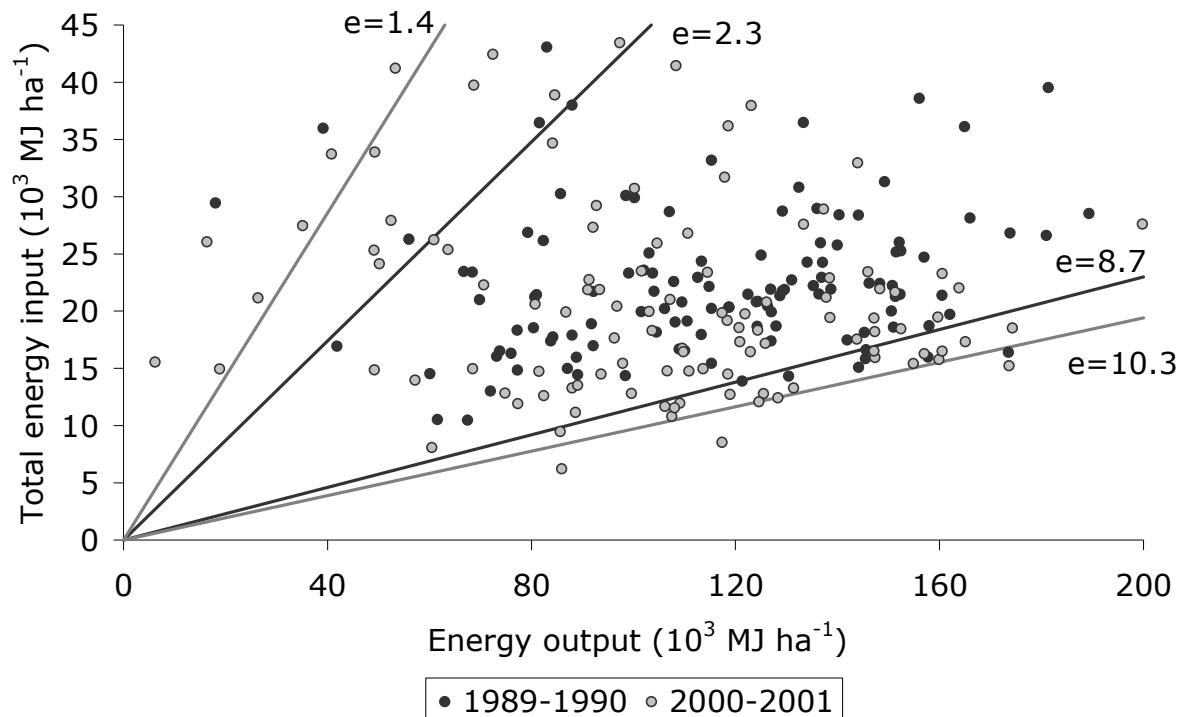


Figure 3.3. Energy output in relation to energy input on Flemish specialised arable farms in 1989–1990 and 2000–2001. Lines are isoquants of energy ratio: e = energy ratio (energy output/input; no units)

Table 3.7 shows that the average energy input of a group of 12 top performing arable farms was only 60% of the average energy input of all arable farms, owing to a lower diesel use (-46%) and a lower use of mineral fertilisers (-28%); while the energy output was 22% higher. The result was an energy ratio twice as high as the average energy ratio of all arable farms. The high energy use efficiency of the best farms was highly determined by the grown crops: the average share of cereals (mainly winter wheat) was almost 40% higher and the average share of sugar beet was 28% higher. As shown in Table 3.8, cereal crops and sugar beet combine a high energy output per ha with a low energy demand and therefore have a high energy ratio. Farms with a large share of cereals and sugar beet can thus be expected to have a higher energy ratio.

This aspect also explains why the average gross value added of the trendsetting farms was lower than the average of all farms (-8%, Table 3.7): in Flanders, cereals generally have the lowest price of all arable crops, the most lucrative crops being vegetables.

Since the energy ratio is highly influenced by the grown crops, specific target values should be set for each separate crop on arable farms, but the FADN data are not enough detailed to apply this method.

Table 3.7. Average characteristics of the specialised arable farms in the FADN and of a subgroup of 12 top performing farms with regard to energy ratio (data of 1989, 1990, 2000 and 2001)

Topic	Top performing farms	All farms	Top performing farms compared to all	
	n = 12	n = 229	Absolute	Relative (%)
Cultivated area (CA) (ha)	39.0	56.7	-17.7	68.8
Cereals in CA (%)	47.4	34.0	13.4	139.4
Sugar beet in CA (%)	22.1	17.3	4.8	127.8
Energy input (MJ ha ⁻¹)				
Diesel	4271	7923	-3652	53.9
Lubricants	226	539	-313	41.9
Electricity	352	1073	-721	32.8
Other sources	181	424	-243	42.7
Mineral fertiliser	5910	8179	-2269	72.3
Seeds	373	474	-101	78.7
Pesticides	706	1239	-533	57.0
Machines	895	1949	-1054	45.9
<i>Total</i>	<i>12914</i>	<i>21800</i>	<i>-8886</i>	<i>59.2</i>
Energy output (MJ ha ⁻¹)	136694	112397	24297	121.6
Energy ratio	10.6	5.2	5.4	205.3
Gross value added (€ ha ⁻¹)	1061	1160	-99	91.5

Table 3.8. Energy ratio (output/input) for the production of major arable crops (according to Hülshbergen et al., 2001)

	Potato	Cereals	Sugar beet
Energy input (MJ ha ⁻¹)	24430	14660 - 19330	29700
Energy output (MJ ha ⁻¹)	105100	144600 - 278800	330100
Energy ratio	4.3	9.4 - 14.4	11.1

3.3.3. Discussion

3.3.3.1. The use of efficiency indicators

Many studies have been carried out on energy use in agriculture, and many of them involve the use of energy productivity or energy ratio as indicators of energy use efficiency (Halberg, 1999; Koskamp et al., 2000; Hulsbergen et al., 2001). These indicators comply with the principle of eco-efficiency – to produce more from less – which was identified as a major principle of ecological sustainable agricultural systems in Flanders (Nevens et al., 2007).

A major drawback of this efficiency approach is the potential compensation of negative effects by positive gains (Pervanchon et al., 2002). For example, if a farmer A uses twice the energy amount of farmer B and produces twice the amount of output in comparison with B, A and B would have the same energy use efficiency, whereas A uses more energy than B. Such compensations may not be acceptable with regard to sustainability, since a given level of energy use may overpass a threshold of acceptable environmental impact. However, according to our knowledge, until today no such threshold value for energy use on Flemish farms can be established. Moreover, in our study, the average energy use of the most energy efficient farms was lower than the average energy use of all studied farms. This shows that these farms could realise a higher output with a lower energy use, so there was no compensation. Therefore, we do consider the use of efficiency indicators justified to evaluate and compare Flemish farms.

Pervanchon et al. (2002) also emphasize that crop yields may vary significantly between fields, between farms and from year to year due to climatic variations or pests. This may induce differences in the results of the ratio indicator on arable farms and hide differences due to management. However, on the studied arable farms of the Flemish FADN, the higher energy output of the top performing farms can not be attributed to more optimal weather conditions, since the group of best performing farms, as well as the group of lowest performing farms (with lowest energy efficiency – not mentioned in Table 3.7) both contained farm data from all considered years (1989, 1990, 2000 and 2001). However, it is recommended to be vigilant about these significant potential influences of environmental conditions on the energy use efficiency, particularly on arable farms.

3.3.3.2. How to guide farms towards a higher sustainability level?

For each farm type we extracted a group of best performers (5% of the total set) that showed the highest energy use efficiency. A detailed description of the characteristics and operational management aspects of those top performing farms could allow an identification of the specific farm aspects underlying their

remarkably good energy efficiency performances. Those farms could then be set as an example for others and be used in education and extension projects. Examples of such 'learning networks' can be found in a number of Dutch projects: 'De Marke' (Anonymous, 2003), 'AP-Minderhoudhoeve' (Overvest, 2002), 'Koeien en Kansen' (Oenema, 2003; De Vries, 2003), 'Bioveem' (Snijders and Everts, 2000) and 'Vel & Vanla' (Van der Hem, 2003).

Besides that, an indicator-based farm evaluation system can be a helpful instrument to guide farms towards a higher level of sustainability. Several systems focussing on ecological sustainability are in use: Wetterich and Haas (1999) in Germany, Van Zeijts et al. (1999) in The Netherlands and Lewis and Bardon (1998) in the UK. More holistic systems also include indicators for social and economic sustainability: Rigby et al. (2001) in the UK and Vilain (2000) in France. Depending on the system, indicator benchmarks are based on average values, comparable farms, top performers or pre-defined optima.

3.4. Conclusions

We calculated total energy use on a representative set of Flemish specialised dairy, arable and pig farms and we studied the changes in energy use and energy use efficiency at farm level between 1989 and 2001. The results showed that indirect energy use, particularly the use of mineral fertilisers and animal feed, accounts for a high share of the total energy use on the farms. Diesel use takes the major part of direct energy use. Therefore, decreasing the energy use on farms should not only be tackled by a lower diesel use, but also by lower uses of farm inputs like mineral fertilisers and concentrates.

We calculated energy productivity on dairy and pig farms as a measure of energy use efficiency. For both farm types, the most energy efficient farms were intensive farms, which combine a high production with a low energy use. Compared to the average of all farms, the most energy efficient farms had a comparable or even higher gross value added per unit of production.

Based on the energy productivity values of the top 5% farms, we propose target values of 35 l milk 100 MJ⁻¹ and 7.5 kg live weight 100 MJ⁻¹ for energy use on Flemish dairy farms and farrow-to-finish pig farms, respectively. On arable farms, the energy ratio (as a measure of energy use efficiency) was highly dependent on the grown crops. For that reason, we recommend to calculate energy ratios at field level for each separate crop, instead of at farm level. However, to achieve this, a lot of detailed information on the used amounts of inputs for each separate crop will be necessary.

Chapter 4

Making eco-efficiency concrete on Flemish dairy farms



Redrafted after:

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Abstract

Eco-efficiencies of a representative set of Flemish dairy farms were determined for the years 1989–1990 and 2000–2001. Eco-efficiency was measured as a combination of nitrogen (N) use efficiency and energy use efficiency, where N use efficiency (l milk kg⁻¹ N surplus) is the ratio between the amount of produced milk and the farm-gate N surplus (= N input – N output). Energy use efficiency (l milk 100MJ⁻¹) is the ratio between the amount of produced milk and the total (direct + indirect) energy input. Between 1989–1990 and 2000–2001, average N use efficiency increased from 27 to 40 l milk kg⁻¹ N surplus and average energy use efficiency increased from 22 to 27 l milk 100MJ⁻¹, indicating an overall increase of eco-efficiency of the Flemish dairy farms during those periods. The farms with the highest eco-efficiencies were characterised by a higher milk production, a lower N surplus, a lower energy input and a higher gross value-added. The latter shows that on the studied farms, eco-efficiency went hand in hand with better economic results.

Keywords: Dairy farming; Eco-efficiency; Energy use efficiency; Flanders; Nitrogen use efficiency.

Making eco-efficiency concrete on Flemish dairy farms

4.1. Introduction

'Eco-efficiency' is a management approach that was acknowledged at the 1992 Rio Earth Summit as a way for companies and businesses to contribute to sustainable development (de Jonge, 2004). Eco-efficiency has been given many definitions, all of them, however, adding up to the one principle 'produce more from less' or adding maximum value with minimum use of resources and with minimum environmental impact (WBCSD, 2000; Jollands et al., 2004). The measurement of eco-efficiency is typically expressed as the eco-efficiency equation, which is the product or service value divided by the environmental influence. The generally applicable indicators for product or service value are: quantity of goods or services produced or provided to customers and net sales. Those relating to the environmental influence are: energy consumption, materials consumption, water consumption, greenhouse gas emissions and ozone-depleting substance emissions (Verfaillie and Bidwell, 2000).

Also in the agricultural business, efficient use of resources is one of the major assets of sustainable production. In this study we focus on two excessively used resources in agricultural production systems: nutrients and energy. Besides economic consequences, inefficient use of those resources can result in severe environmental impacts: an excessive loss of nutrients enriches the natural environment and negatively influences biodiversity; the emission of greenhouse gases by combustion of fossil fuels contributes to climate change.

4.1.1. Nutrient use efficiency

For a specific nutrient (e.g., nitrogen, N), a farm-gate balance summarises inputs and outputs from a single farm. The calculated N surplus (inputs – outputs) relates well to modelled or measured N losses (Jarvis and Aarts, 2000) and can thus be considered as a useful and reliable indicator to assess the potential negative environmental impacts of N use (Nevens et al., 2006). We calculated the eco-efficiency equation as the ratio between the farm's product outputs (e.g., litres of produced milk on a dairy farm) and the N surplus. We further define this ratio as the N use efficiency.

4.1.2. Energy use efficiency

Potential environmental impacts of energy use can be assessed by calculating the sum of all consumed 'direct' and 'indirect' energy on a farm. Direct energy use consists of the energy used on the farm for field and livestock operations, while indirect energy is the energy that is used to produce farm inputs. We defined energy use efficiency as the ratio between the farm's product outputs and the total energy used for their production. This ratio can be used as a second measure of eco-efficiency.

The aim of our study was to make eco-efficiency concrete for dairy farms, based on N use and energy use. We calculated eco-efficiencies of a representative set of specialised dairy farms in Flanders and we studied the changes between 1989–1990 and 2000–2001. Finally, we determined the main factors or farm characteristics that influence the eco-efficiency of Flemish dairy farms. Since we only had access to average farm characteristics of anonymous farms, we were not able to consider any organisational, management or other decision-making aspects.

4.2. Materials and methods

4.2.1. Data and farm characteristics

The Flemish Farm Accountancy Data Network (FADN) is a database of technical and economic data from a representative set of Flemish farms. From this dataset we extracted the entries of the specialised dairy farms (i.e., farms on which at least 95% of the farm income originates from dairy activity) in 1989, 1990, 2000 and 2001. A selection of average characteristics of the farms is presented in Table 4.1.

4.2.2. N surplus and N use efficiency

Figure 4.1 presents the inputs and outputs that were considered in the farm-gate N balance (on an annual basis). Total N input is the sum of N in purchased concentrates, forages and by-products, straw (or sawdust), animals, mineral fertiliser and manure, in biological fixation and in atmospheric deposition. Total N output is the total amount of N in exported milk, animals, manure and crops. All inputs and all outputs are expressed in kg N per ha of total utilised farm area. The farm-gate N surplus was calculated as total N input – total N output. The farm N use efficiency was defined as the ratio of milk production to farm-gate N surplus and hence was expressed as l milk kg⁻¹ N surplus.

For all considered farms, we calculated the farm-gate N surplus based on the FADN data. For a detailed description of the calculation method, we refer to Nevens et al. (2006).

Table 4.1. A selection of average characteristics of specialised dairy farms in the dataset extracted from the Flemish Farm Accountancy Data Network (1989, 1990, 2000 and 2001)

Characteristic	Unit	1989 n = 169	1990 n = 165	2000 n = 78	2001 n = 69
Utilized area	ha	27.6	27.8	32.1	32.4
Share of grassland	%	70	70	64	63
Annual values					
Concentrate use	kg cow ⁻¹	1236	1169	1158	1132
Mineral fertilization	kg N ha ⁻¹				
on grassland		309	287	213	186
on arable land		98	94	57	40
Milk production	litre				
per cow		5319	5365	6017	5827
per ha		9607	9567	10043	9643
Stocking density ^(a)	LU ha ⁻¹ ^(b)	3.02	3.08	3.04	2.98

^(a) Stocking density is expressed on the total area of the farm, i.e., including arable land.

^(b) 1 Livestock Unit (LU) is the equivalent of one milking cow with a production level of 4000 l year⁻¹; each extra production of 1000 l year⁻¹ adds 0.1 LU.

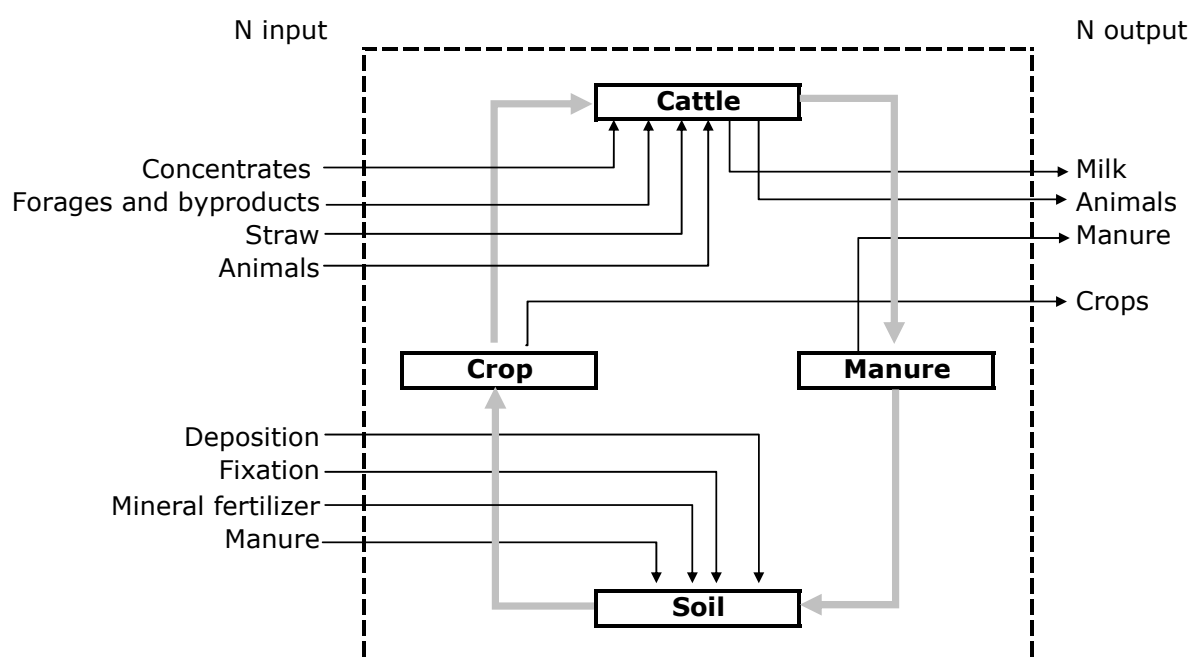


Figure 4.1. Farm-gate N balance: considered inputs and outputs of nitrogen (source: Nevens et al., 2006)

4.2.3. Energy use and energy use efficiency

Jones (1989) presented a hierarchy of methods for energy use analysis in agro-ecosystems, based on the applied system boundaries. The method used in our study corresponds to 'process analysis', where all energy inputs (direct and indirect) to an agricultural system are considered, based on physical material flows. Human labour and solar energy are not considered in this method. We only included indirect energy use one step backwards from the farm. This means that we included, e.g., the energy used to produce fertilisers, but not the energy used to manufacture the equipment to produce the fertilisers. According to Refsgaard et al. (1998), by applying these boundaries, over 90% of the total energy input in the production process of farm inputs is covered. We considered the energy used up to the point where the products leave the farm, called the 'farm-gate approach' (Corré et al., 2003), which means that the energy required for packing, drying, storing and transporting products from the farm to consumers was not taken into account.

Total energy input was expressed in megajoule (MJ) and was calculated as the sum of all direct and indirect energy inputs to a farm. Direct energy input consisted of diesel (including contract work diesel), lubricants, electricity and other energy carriers (e.g., gas). The accounted energy was the caloric energy content (this is the amount of energy released when the fuel is combusted) and the energy used for mining, transformation and transport of the energy carrier. Indirect energy input to the farm included the energy needed for the production and transportation of mineral fertilisers, seeds, pesticides, concentrates, forages and field machinery. All energetic values used in our study were based on scientific literature and are summarised in Table 4.2.

Total direct and indirect energy inputs to the considered farms were calculated on an annual basis by multiplying the consumed amounts of inputs – extracted from the FADN – by their corresponding energetic values. The farm energy use efficiency was calculated as the amount of produced milk per 100MJ of total energy input and was thus expressed as l milk 100MJ⁻¹.

Table 4.2. Energetic values of production inputs

Input	Energetic values		Reference ^(a)
Direct energy			
Diesel	40.68	MJ l ⁻¹	a,b,c,d,e,f,g
Lubricants	3.6	MJ l ⁻¹ diesel ^(b)	a
Electricity	5.65	MJ kWh ⁻¹	d,e,h,i
Indirect energy			
Field crops			
Seeds ^(c)			
Winter wheat	571	MJ ha ⁻¹	c,j,k
Sugar beet	419	MJ ha ⁻¹	c,l,m
Potato	1300	MJ ha ⁻¹	c,n
Maize	168	MJ ha ⁻¹	b,o
Grass	132	MJ ha ⁻¹	b,k
Mineral fertilizer			
N	55.3	MJ kg ⁻¹	a,b,c,p,q
P ₂ O ₅	15.8	MJ kg ⁻¹	c
K ₂ O	9.3	MJ kg ⁻¹	c
Pesticides			
Fungicides	276	MJ kg ⁻¹ AI ^(d)	a,b,c
Herbicides	214	MJ kg ⁻¹ AI	a,c,p
Insecticides	278	MJ kg ⁻¹ AI	a,c
Machinery	12	MJ l ⁻¹ diesel	a
Animal production			
Concentrates	6.3	MJ kg ⁻¹	o
Maize silage	2.2	MJ kg ⁻¹ DM ^(e)	b,o
Grass silage	1.5	MJ kg ⁻¹ DM	o

^(a) a: Dalgaard et al. (2001); b: Wells (2001); c: Hülsbergen et al. (2001); d: Maertens and Van Lierde (2003); e: Vito (2004); f: Australian Institute of Energy (2004); g: Boustead (2003); h: EMA (2002); i: FPS Economy (2004); j: Refsgaard et al. (1998); k: Dekkers (2002); l: Ministry of Agriculture (2001); m: Bonnez (Iscal Sugar nv., pers. comm.); n: PCA (Interprovinciaal Proefcentrum voor de Aardappelteelt, pers. comm.); o: de Haan and Feikema (2001); p: Gezer et al. (2003); q: Gliessman (2000). In case of multiple references, average values were used.

^(b) The energy input from lubricants and the energy needed for production of field machinery is related to the amount of diesel used during field operations.

^(c) We computed the energy required to produce the amount of seed necessary to grow 1 ha of the crop.

^(d) AI = active ingredient.

^(e) DM = dry matter.

4.3. Results and discussion

4.3.1. N surplus and N use efficiency

Table 4.3 shows the average components of the farm-gate N balance of the FADN dairy farms in 1989–1990 and 2000–2001. These results illustrate that the farm-gate N surplus is highly determined by the use of mineral fertilisers and concentrates: together they represented 70% of total N input in 2000–2001.

Table 4.3. Flemish dairy farms in 1989–1990 and 2000–2001: average components of the N balance ($\text{kg N ha}^{-1} \text{ year}^{-1}$) and their evolution

	'89-'90	'00-'01	'00-'01 compared to '89-'90	
	b	a	Absolute change b-a	Relative change (b-a)/a (%)
N input				
Mineral fertiliser	238	144	-94	-40
Concentrates	99	83	-16	-16
Manure	25	25	0	-0.4
Straw	2	2	0	2
Forages, byproducts	28	20	-8	-29
Deposition	50	48	-2	-4
Fixation	1	6	5	352
Total	442	327	-115	-26
N output				
Milk	48	52	4	7
Animals*	20	18	-2	-10
Crops	1	3	2	152
Total	69	73	3	5
N surplus	369	250	-119	-32

* Net result of sold animals minus purchased animals.

The average annual N surplus of the FADN dairy farms decreased from 369 kg ha^{-1} in 1989–1990 to 250 kg ha^{-1} in 2000–2001 (Table 4.3). This reduction of the N surplus (-119 kg ha^{-1}) was almost solely due to a major reduction of N input (-115 kg ha^{-1} or -26%), primarily of mineral fertiliser (-94 kg ha^{-1}) and of concentrates (-16 kg ha^{-1}). N output ha^{-1} (mainly associated with milk production) hardly changed.

Figure 4.2 shows the N surplus (kg N ha^{-1}) in relation to the milk production (l ha^{-1}) for all considered dairy farms. In 1989–1990, 90% of the set of specialised dairy farms operated between N use efficiency isoquants of 15 and 40 l milk kg^{-1} N surplus; the average was 27 l milk kg^{-1} N surplus. In 2000–2001, 90% of the

dairy farms operated at 20 to 60 l milk kg⁻¹ N surplus, with an average of 40 l milk kg⁻¹ N surplus. This corresponds with an increase in average N use efficiency of 48% between 1989–1990 and 2000–2001. Considering the decreased N surplus (Table 4.3), the studied dairy farms succeeded in keeping up or even increasing their milk production while substantially lowering their N surplus.

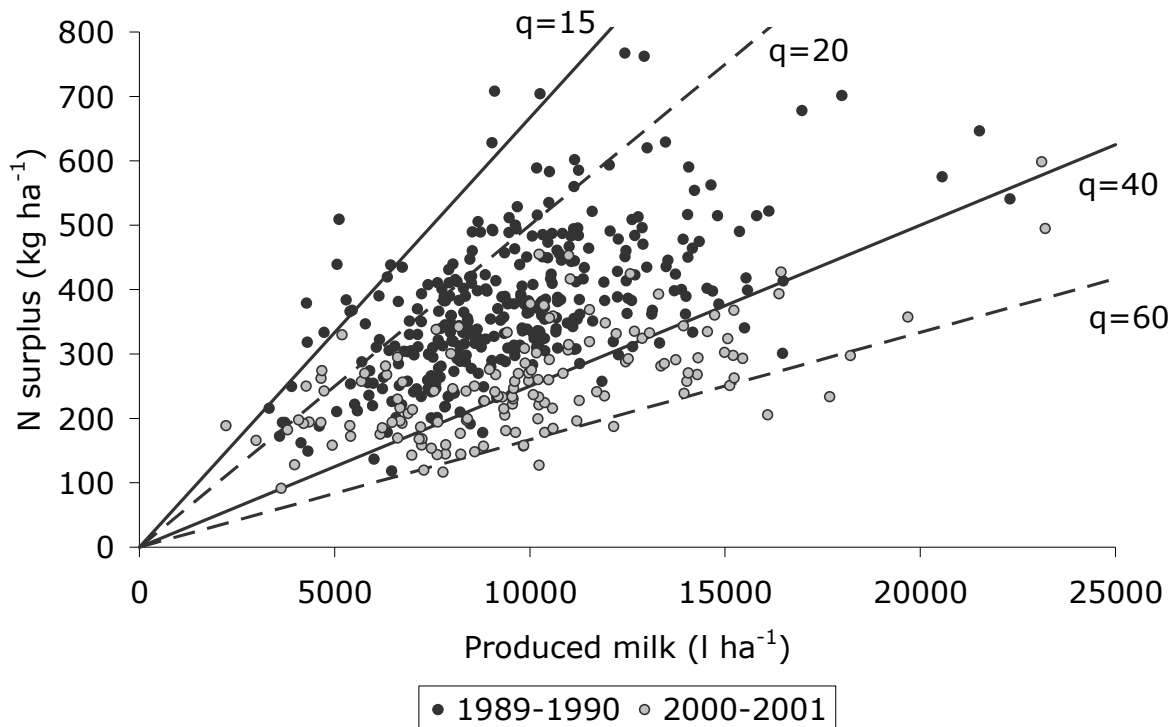


Figure 4.2. Farm-gate N surpluses in relation to produced milk: data of Flemish specialised dairy farms in 1989–1990 and 2000–2001. Lines are isoquants of N use efficiency ($q = \text{l milk kg}^{-1} \text{ N surplus}$)

4.3.2. Energy use and energy use efficiency

In 2000–2001, 67% of total energy input on the FADN dairy farms could be attributed to indirect energy use (Table 4.4). Particularly the use of mineral fertilisers and concentrates accounted for a high share (about 60%) of the total farm energy input. Diesel use took the major part of direct energy input and accounted for about 22% of total energy use in 2000–2001.

The average annual energy use of the FADN dairy farms decreased by nearly 20%, from 45 055 MJ ha⁻¹ in 1989–1990 to 36 372 MJ ha⁻¹ in 2000–2001 (Table 4.4). Similar to the N surplus, this decrease (–8683 MJ ha⁻¹) can be attributed to mineral fertilisers (–6185 MJ ha⁻¹) and concentrates (–2285 MJ ha⁻¹).

Table 4.4. Flemish dairy farms in 1989–1990 and 2000–2001: average components of energy input ($\text{MJ ha}^{-1} \text{ year}^{-1}$) and their evolution

	'89-'90 b	'00-'01 a	'00-'01 compared to '89-'90	
			Absolute change b-a	Relative change (b-a)/a (%)
Direct energy input				
Diesel	7422	8044	622	8
Lubricants	524	534	10	2
Electricity	4345	3458	-887	-20
Other sources	149	109	-40	-27
Total	12439	12144	-295	-2
Indirect energy input				
Mineral fertiliser	14549	8364	-6185	-43
Seeds	165	163	-2	-1
Pesticides	189	220	31	16
Machinery	2228	2424	196	9
Concentrates	15182	12897	-2285	-15
Forages	302	161	-141	-47
Total	32616	24228	-8388	-26
Total energy input	45055	36372	-8683	-19

Figure 4.3 shows the total energy input (MJ ha^{-1}) in relation to the milk production (l ha^{-1}) of the dairy farms. In 1989–1990, 90% of the set of specialised dairy farms operated between energy use efficiency isoquants of 14.5 and 30.0 $\text{l milk } 100\text{MJ}^{-1}$; the average was 21.6 $\text{l milk } 100\text{MJ}^{-1}$. In 2000–2001, 90% of the dairy farms operated at 16.7 to 39.0 $\text{l milk } 100\text{MJ}^{-1}$, with an average of 27.1 $\text{l milk } 100\text{MJ}^{-1}$. This corresponds with an increase in energy use efficiency of 25% between 1989–1990 and 2000–2001. Considering the decreased total energy use (Table 4.4), the studied dairy farms succeeded in keeping up or increasing their milk production with a substantially lower energy use.

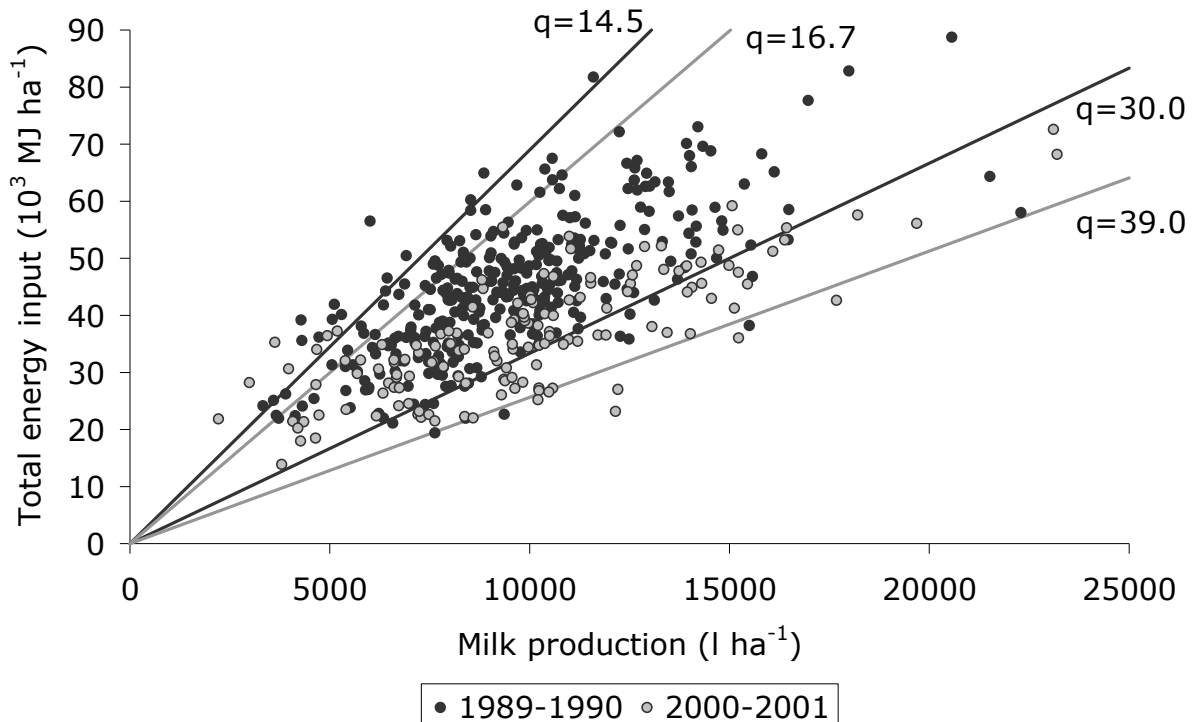


Figure 4.3. Energy input in relation to produced milk: data of Flemish specialised dairy farms in 1989–1990 and 2000–2001. Lines are isoquants of energy use efficiency ($q = \text{l milk } 100 \text{ MJ}^{-1}$)

4.3.3. N use efficiency versus energy use efficiency

Figure 4.4 shows a positive relationship between the N use efficiency and the energy use efficiency of the Flemish dairy farms (data from 1989, 1990, 2000 and 2001). This makes sense, since both the farm-gate N balance and the farm-gate total energy use are dominated by the use of mineral fertilisers and concentrates. The average N use efficiency, as well as the average energy use efficiency of the Flemish dairy farms increased between 1989–1990 and 2000–2001, which is visualised by the arrow in Figure 4.4.

Farms that achieve the highest level of eco-efficiency combine a high N use efficiency with a high energy use efficiency. The ten best performing farms (pragmatic choice) from our dataset are located in the upper-right quadrant of Figure 4.4. These best performing farms established an N use efficiency of at least $52 \text{ l milk kg}^{-1} \text{ N surplus}$ and an energy use efficiency higher than $35 \text{ l milk } 100 \text{ MJ}^{-1}$. In Table 4.5 some average characteristics of those top performing farms are compared with the average characteristics of all FADN specialised dairy farms. The results show that the average N use efficiency of the top performing farms was twice as high as the overall average, while the energy use efficiency was 69% higher. This was achieved by a combination of a higher milk production per ha (+34%, result of a higher milk production per cow and a higher stocking

density), a lower N surplus (-36%) and a lower energy use (-21%). The lower N surplus and lower energy input were achieved owing to a lower use of mineral fertilisers, concentrates and diesel (Table 4.5). These results show that the high eco-efficiency of these farms is achieved, by simultaneously producing a higher output *and* having a lower environmental impact.

Moreover, the top performing farms realised a gross value-added that was $6.4 \text{ € } 100\text{l}^{-1}$ milk (or 29%) higher than the average value. These data illustrate that for the studied dairy farms, an eco-efficient management could be combined with good economic results.

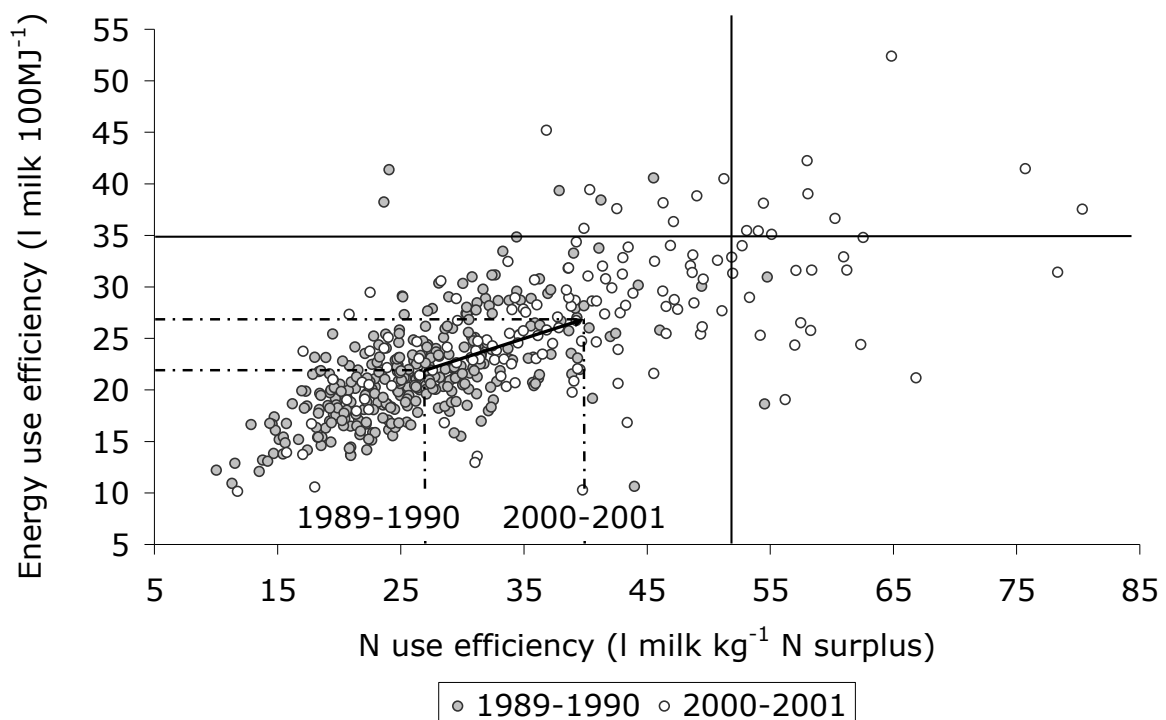


Figure 4.4. Energy use efficiency in relation to N use efficiency: data of Flemish specialised dairy farms in 1989–1990 and 2000–2001. Upper-right quadrant consists of the farms with the highest levels of eco-efficiency

Table 4.5. Average characteristics of the specialised dairy farms in the FADN and of a subgroup of ten top performances with regard to eco-efficiency (data of 1989, 1990, 2000 and 2001)

Characteristic	Unit	Top performing farms	All farms	Top performing farms compared to all	
		n = 10 (b)	n = 481 (a)	Absolute change b-a	Relative change (b-a)/a (%)
Utilised area	ha	36.7	29.1	7.5	26
Mineral fertiliser use	kg N ha ⁻¹	113	209	-96	-46
Concentrate use	kg ha ⁻¹	2087	2299	-212	-9
Diesel use	l ha ⁻¹	166	187	-21	-11
Stocking density	LU ha ⁻¹	3.14	3.03	0.11	4
Milk production	l cow ⁻¹	6501	5523	978	18
	l ha ⁻¹	12997	9669	3328	34
N surplus	kg ha ⁻¹	215	337	-122	-36
Total energy input	MJ ha ⁻¹	33405	42402	-8997	-21
N use efficiency	l milk kg ⁻¹ N surplus	61.4	30.7	30.7	100
Energy use efficiency	l milk 100MJ ⁻¹	39.3	23.3	16.0	69
Gross Value Added	€ 100l ⁻¹ milk	28.7	22.3	6.4	29

4.4. Conclusions

In this study, we made eco-efficiency concrete for dairy farms in Flanders, based on the farms' N use efficiencies and energy use efficiencies. A high level of eco-efficiency on Flemish dairy farms could be achieved by a combination of:

- a high milk production (per ha), realised by a high milk production per cow, either combined or not with a high stocking density
- a low N surplus, realised by a limited use of mineral fertilisers and concentrates
- a low energy input, realised by a limited use of mineral fertilisers and concentrates and a limited diesel use.

For the studied dairy farms, a high eco-efficiency was achieved by simultaneously producing a higher output *and* having a lower environmental impact.

During the past 20 years, Flemish dairy farms have considerably improved their eco-efficiency: between 1989–1990 and 2000–2001, average N use efficiency increased from 27 to 40 l milk kg⁻¹ N surplus and average energy use efficiency increased from 21.6 to 27.1 l milk 100MJ⁻¹. This study also shows that increasing eco-efficiency can go hand in hand with good economic results, since the farms with the highest level of eco-efficiency also realised the highest gross value-added.

Despite this positive evolution of eco-efficiency, we think that in truly sustainable (agricultural) systems, unsustainable flows or negative environmental impacts should not only be reduced, but radically eliminated (McDonough and Braungart, 2002). Therefore, totally new production systems (e.g., without the use of mineral fertilisers, chemicals or fossil fuels) should be considered and/or designed.

Chapter 5

MOTIFS: A monitoring tool for integrated farm sustainability



Redrafted after:

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Abstract

Indicator-based monitoring tools are frequently applied for sustainability assessments, also in agriculture. However, many of them focus on a rather restricted number of sustainability aspects, in general economic and/or ecological, and only in few cases the choice of indicators is explained. The aim of our study was to develop an indicator-based monitoring tool for integrated (i.e. taking into account economic *and* ecological *and* social aspects) farm sustainability, based on a supported vision on sustainable agriculture and using a set of relevant indicators. Hereby, specific attention was paid to aspects of communication and user-friendliness. Four methodological steps were considered: (i) translating the major principles of a supported vision on sustainable Flemish agriculture into concrete and relevant themes; (ii) designing indicators to monitor progress towards sustainability for each of those themes; (iii) aggregating the indicators into an integrated farm sustainability monitoring tool and (iv) applying the monitoring tool on a practical farm, as a first attempt of end-use validation. Stakeholder participation and expert consulting took an important place in each of these methodological steps. As a case study, the methodology was applied to Flemish dairy farms. As a result, we developed MOTIFS, a user-friendly and strongly communicative instrument to measure progress towards integrated sustainable dairy farming systems, that fits within a well founded methodological framework and that is based on a set of relevant indicators. MOTIFS is based on the equality of the economic, ecological and social sustainability dimension and this equality is inherently built into the system. Through the applied methodology, we founded the selected themes and indicators and we avoided using indicators that are not relevant for the problem at hand.

Keywords: Aggregation, Dairy farms, Indicators, Integrated sustainability, Monitoring, Flanders

MOTIFS: A monitoring tool for integrated farm sustainability

5.1. Introduction

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). This 'Brundtland-definition' is known worldwide, and has rightfully gained its place in the vision, mission and strategy of companies, organizations and governments. However, putting the theoretical concept into practice, into actual measures and actions, often proves to be very difficult - also in agriculture. A useful tool to effectively solve this 'sustainability paradox' between theory and practice, is a framework that considers sustainable development as a long-term, complex and drastic process of change (a 'transition'; Rotmans, 2003; Geels, 2005). This framework consists of four actions: (i) developing a vision, (ii) establishing one or more strategies, (iii) taking action and (iv) monitoring progress. A vision describes images of an envisioned, sustainable future. Strategies align possible paths from the current situation towards the envisioned future and serve as a decision-base for taking actions. Finally, a monitoring instrument, e.g. a set of indicators or a model, is used to follow up whether running or anticipated actions actually contribute to achieving the objectives defined by the vision. The aim of the presented work fits in this final step of the sketched process: developing a monitoring tool, in our case specifically designed to effectively advise Flemish farmers on several aspects of farm sustainability and hence to guide them towards more sustainable ways of agricultural production.

Indicators are often used in sustainability monitoring (Bell and Morse, 1999). For agriculture, indicator-based farm monitoring tools already exist and are applied in practice. In such tools, indicators are used (i) individually, (ii) as part of a set, or (iii) combined into a composite index (Farrell and Hart, 1998). Since individual indicators are of limited use to adequately represent all essential aspects of a complex system's viability and sustainability, a balanced set of indicators is preferred (Bossel, 1999). Hereby, a graphical presentation of multiple indicator scores is often used, allowing a comprehensive overview and mutual comparison of the indicators for different sustainability aspects. Examples of such a 'visual integration' are radar graphs (Gomez et al., 1996; Bockstaller et al., 1997; Rigby et al., 2001) or bar graphs (Lewis and Bardon, 1998). Graphic methods can be used as decision aid tools, to measure and compare farm progress towards a

more sustainable agriculture and they are considered well suited for an effective communication about sustainability. Aggregating indicator values into a single composite index ('numerical integration', e.g. Taylor et al, 1993) has been found particularly useful to compare policy options and to inform the public and decision makers on the sustainability of a system (Farrell and Hart, 1998). This method summarizes complex or multi-dimensional issues and provides the big picture, without the danger of information overload (Jollands et al., 2004). However, the lack of transparency of highly aggregated indices can be a serious problem (Bell and Morse, 2003), possibly leading to misinterpretations. A somewhat particular method of numerical integration is the Sustainable Value Added (SVA) approach (Figge and Hahn, 2004; Van Passel et al., 2007), in which the single composite index is expressed in monetary terms. It is obvious that both method types – visual and numerical integration – can be combined (e.g. Girardin et al., 2000).

An overview of existing monitoring tools used in agriculture, learns that many of them focus on a rather restricted number of sustainability aspects, in general economic and/or ecological (von Wirén-Lehr, 2001). Such tools can not be used to genuinely evaluate a farm's integrated sustainability, i.e. taking into account economic, ecological as well as social aspects. Another striking observation, is that only few authors explain how and why the considered sustainability aspects and indicators were selected (van der Werf and Petit, 2002).

The aim of our study was to develop an indicator-based monitoring tool for integrated farm sustainability, that is based on a supported vision on sustainable agriculture and uses a set of relevant indicators. Since we aspire that the developed monitoring tool will be used in practice as a management guiding tool, we paid specific attention to aspects of communication and user-friendliness. In this paper, we describe the applied methodology for developing this monitoring tool and we illustrate its practical use on a Flemish dairy farm as a case study. We considered four successive steps:

- translation of the major principles of a supported vision on sustainable Flemish agriculture into concrete and relevant themes for individual farms;
- design of indicators to monitor progress towards sustainability for each of those themes;
- aggregation of the indicators into an integrated farm sustainability monitoring tool;
- application of the monitoring tool on a practical farm, as a first attempt of end-use validation.

5.2. Materials and methods

5.2.1. Translating a vision into concrete and relevant themes

Sustainable development processes should be based on a well-conceived vision, with concrete and inspiring images of an envisioned future (Hardi and Zdan, 1997). Nevens et al. (2005, 2007) describe a process of vision development on a sustainable (future of) agriculture in Flanders. This process was based on a transdisciplinary dialogue between the many stakeholders of Flemish agriculture. We considered the resulting vision - 'On tomorrow's grounds' – as a publicly supported guideline for all actors (including farmers, agricultural industry, consumers and government). It integrates major principles for the ecological, the economic and the social sustainability dimension of agricultural systems. In mutual agreement with stakeholders, we translated those major principles into concrete themes to make 'sustainability' more tangible at a practical level, to be able to take directed actions and to design relevant indicators.

5.2.2. Designing indicators

To further concretize the selected sustainability themes, we designed relevant indicators.

5.2.2.1. Indicator criteria

According to the International Institute for Sustainable Development (Bossel, 1999), an indicator quantifies and simplifies phenomena and complex realities to a manageable amount of meaningful information, feeding decisions and directing actions. In other words, in our study the indicators should give a clear signal for appropriate action and hence guide farmers' management towards a higher level of sustainability. Considering their effectiveness, we imposed a number of criteria for the indicators:

- there is an obvious and well defined relationship between an indicator and the phenomenon to monitor (causality);
- a change in the situation is reflected in a value change of the indicator (sensitivity);
- the well-documented calculation method of the indicator value minimally depends on external factors (solidness);
- benchmarks are available to evaluate the indicator value (use of benchmarks);
- indicator values and scores are easily interpretable (comprehensibility).

5.2.2.2. Indicator selection and design

Extended literature is available on the development and use of indicators to measure farm sustainability. In a majority of cases, they address ecological and/or economic aspects. Whenever such existing indicators complied with our supported vision, the derived themes and the imposed quality criteria, we integrated them in our monitoring tool. When little or no scientific information was available - which was particularly the case for the social themes - we consulted stakeholders (including experts) for selecting or designing relevant indicators, again taking into account the pre-defined quality criteria. This approach of consulting stakeholders and experts for assessing the relevant indicators of ecological, economic and social sustainability was also successfully applied by van Calster et al. (2005). For some social aspects of sustainable farming, neither scientific information, nor expert knowledge was available. In these cases, new fundamental research was performed (e.g. Dessein and Nevens, 2007).

5.2.2.3. Data availability

Since we aim that the monitoring tool will be used in practice to guide farmers' actions, practical applicability is a major concern. Therefore, to calculate indicator values, we maximally used data that are readily available on farms, or that entail minimum extra costs and/or efforts to collect. Some indicators require quantitative farm data, e.g. amounts of inputs used, amounts of produced products, soil organic matter content, while others are based on qualitative data, e.g. from questionnaires or checklists.

5.2.2.4. Indicator scores

For each of the selected indicators, we defined minimum (B_{\min}) and maximum (B_{\max}) benchmarks, enabling us to rescale indicator values into scores between 0 (indicating a worst-case situation) and 100 (indicating assumed sustainability). This rescaling allows for a mutual comparison of indicators for different aspects of sustainability. We applied several approaches to define benchmark values:

- Scientific knowledge and/or legislative standards: e.g. a farm 'nitrogen (N)-surplus' of 150 kg ha^{-1} (B_{\max}) or less is compliant with the European Nitrates Directive on soil water protection (Nevens et al., 2006).
- The indicator values of a reference group of comparable farms: the 10% best performing farms (pragmatic choice) delimit the 100 score (B_{\max}), the 10% lowest performing farms the 0 score (B_{\min}). Intermediate indicator values are transferred into linearly intermediate scores. In this study, we used dairy farm

data of the Flemish Farm Accountancy Data Network (FADN⁵) as a reference group.

- A production possibility curve: this curve represents the maximum attainable productivity of a farm (Van Passel et al., 2006). E.g., the score of the indicator 'technical efficiency' equals the ratio (in %) between the farm's actual productivity and the maximum attainable productivity (B_{\max}).
- Best Available Techniques (BAT): the indicator score is defined by the share of techniques of e.g. pesticide or waste water management that are actually applied on the farm, compared to the maximum package of combinable alternatives of BAT (B_{\max}).
- The results of a questionnaire: we applied this method mainly for subjective assessment of social indicators such as 'professional pride', for which a farmer himself determines the score on a scale between 0 (B_{\min}) and 100 (B_{\max}).
- Expert judgement: we applied this method when none of the other approaches were suitable for defining benchmarks, e.g. in the cases of 'landscape management' and 'entrepreneurship'. Based on the farmer's answers to a number of relevant questions, experts placed the farms for the specific theme in a progressive (B_{\max}), an average or a lagging group (B_{\min}) with related scores.

5.2.2.5. Indicator weights

Weighing single indicators for aggregation is often dependent on subjective scoring (von Wirén-Lehr, 2001), and this is also the case in our study. We weighed the indicators according to the assumption that all selected sustainability themes are equally important. This rule takes into account the equality of the economic, ecological and social dimensions. Within a specific theme, we considered all indicators as equally important and consequently assigned them an equal weight, except when – based on expert opinions or on literature reviews – there was considerable proof that particular indicators are in fact more important than others when used to evaluate the sustainability of the specific theme. This was the case for the indicators designed to evaluate a farm's (economic) 'productivity' and for 'soil quality'.

5.2.2.6. Indicator validation

Despite the extended interest in and literature on indicator development, relatively little is known in terms of validation processes (Rigby et al., 2001).

⁵ FADN is a database of technical and economic data from a representative set of Flemish farms.

Bockstaller and Girardin (2003) proposed a methodological framework for indicator validation, considering the following definition: “an indicator is validated if it is well founded and if it achieves the overall objectives or produces the intended effects”. The first part of the definition relates to the scientific quality of the construction or design of the indicator, referred to as ‘design validation’. The second part checks whether the indicators actually achieve the objectives for which they are designed: taking into account the indicator objectives defined by Bossel (1999) mentioned above, this includes an evaluation of the information that is supplied by the indicator output – referred to as ‘output validation’ (Bockstaller and Girardin, 2003) – and an evaluation of the usefulness of the indicator for potential users to make decisions – referred to as ‘end-use validation’. Building on this framework, Cloquell-Ballester et al. (2006) proposed a method for validating environmental and social indicators, considering three stages: a self-validation stage carried out by the ‘working team’ itself to reflect on the correct performance and assure the correct documentation of indicators; a scientific validation stage, integrating independent experts’ judgements; and a social validation stage, integrating stakeholders’ opinion.

We combined the methodological principles proposed by Bockstaller and Girardin (2003) and Cloquell-Ballester et al. (2006) and used a transdisciplinary approach of expert and stakeholder participation (Thompson Klein et al., 2001; Astleithner and Hamedinger, 2003) to carry out the design and output validation of the indicators: we presented each indicator to a feedback group of experts and stakeholders to discuss the indicators’ (perceived) relevance and underlying methodological choices such as indicator design, data use, benchmarks and indicator weights. As a first attempt of end-use validation, we applied the indicators to a Flemish dairy farm in practice, to evaluate their usefulness for potential end-users to make decisions. A more elaborate validation procedure for sustainability indicators is developed and applied in Chapter 6 of this thesis.

5.2.3. Aggregating indicators into an integrated sustainability monitoring tool

Since the aim of our tool is to effectively communicate to farmers and advise them on several aspects of farm sustainability, we chose to aggregate the indicators in a graphical way, where all relevant themes are presented individually, instead of combined into a single aggregated index. We used a multi-level approach to aggregate the indicators: at the lowest level (level 3), the individual indicator scores for each selected sustainability theme are visually aggregated in a graph. At level 2, three graphs give an overview of the sustainability themes within each sustainability dimension: economic, ecological or social. Hereby, each theme’s score is calculated as a weighted average of its individual indicator scores. Finally, a level 1 graph gives an overview of the farm’s overall sustainability, aggregating all selected sustainability themes in one

graph. This multi-level tool allows farmers to start from an overall view of the farm's sustainability (level 1), and zoom in on the underlying themes and indicators into as much detail as desired.

We further focused on a user-friendly and communicative design of the tool by:

- providing the ability to add the average indicator scores of a group of comparable farms. This option is particularly useful for farmers who wish to communicate about their farm sustainability in a discussion group;
- visualising the indicator weights. That way, a farmer can readily distinguish which indicators are considered more or less important when evaluating the sustainability of a specific theme.

5.2.4. Case study: sustainability monitoring at a Flemish dairy farm

We applied the monitoring tool to a practical farm, as a first attempt of end-use validation. The described methodological frame of vision development, defining relevant themes and constructing appropriate indicators applies to all farm types and agricultural sectors. However, the final results, the selected themes and indicators, will be farm or sector specific. For example, a specialised arable farm will not need indicators to evaluate animal health and welfare, since this is not a relevant theme for this specific sector. In this study, we therefore applied the methodology specifically to the dairy sector as an example and we used the monitoring instrument on a specific dairy farm as a case study. This 38 ha farm (of which 17 ha grassland and 18 ha maize), milks a quorum of 593,000 litres with 70 Holstein milking cows. The farmer works full-time at the farm and his mother half-time (resulting in 1.5 labour units); his wife works off-farm. According to Flemish standards, this is a fairly large dairy farm.

5.3. Results

5.3.1. Translating a vision into concrete and relevant themes

The major principles underpinning a supported vision on sustainable agriculture in Flanders can be summarized as follows (Nevens et al., 2005; Nevens et al., 2007).

From an ecological viewpoint, a sustainable agricultural system:

- functions within a stable agro-ecosystem, which can be ensured by (i) optimizing the preconditions for production, i.e. optimizing the quality of natural resources (air, soil, water); (ii) maximally closing physical and

biological cycles; and (iii) preserving a broad ecological base, i.e. maximally maintaining and using biodiversity;

- works at the highest levels of eco-efficiency. According to the principle 'produce more from less', this means that it adds maximum value with minimum use of resources and/or with minimum environmental impact (WBCSD, 2000; Jollands et al., 2004);
- maximizes its positive impacts on the environment, e.g. by green services (biodiversity, nature) and blue services (water management).

From an economic angle, a sustainable agricultural system:

- maximizes its produced value added. The value added should be at least sufficient to remunerate the farm's production factors, e.g. farm labor, capital and land, at a level that is comparable with other economic sectors;
- uses the production factors in the most productive (value added / unit of production factor) and efficient (actual productivity / maximum attainable productivity) way;
- minimizes the risk of farming activities; i.e. the production of value added is minimally impacted by external events, e.g. a change of interest rate or a sharp fall in price of agricultural commodities.

From a social viewpoint, sustainability is conceptualized in three dimensions:

- social inclusion (Cousins, 1999), encompassing a sufficient level of access of farmers to provisions such as housing, income, health, labour and good working conditions, services, facilities, education and financial security;
- identity, enabling a farmer to live according to his/her own values and norms, within the limits of pre-conditions postulated by society;
- social capital, referring to the diverse networks and relations of trust between people involved in agriculture. Social capital strengthens social cohesion and stability within groups of people, organizations or society at large. Hence, it eventually creates a broad social support base for agriculture.

We translated these major principles into 10 relevant themes for sustainable agricultural production:

- (1) use of inputs, (2) quality of natural resources and (3) biodiversity, referring to ecological sustainability;

- (4) profitability, (5) productivity and efficiency and (6) risk, referring to economic sustainability;
- (7) internal social sustainability, which takes the well-being of the farmer and his family as a focal point, (8) external social sustainability, which is related to the expectations of the society vis à vis agriculture and (9) disposable income, referring to social sustainability.
- It is clear that integrating these diverse principles and themes into a farm's management will require a considerable amount of entrepreneurship of the (future) farmers. Therefore, we added entrepreneurship (10) as an additional theme for the sustainability monitor.

5.3.2. The indicators

Table 5.1 summarizes the indicators we designed for each of the ten relevant sustainability themes. For each indicator, a concise definition and methodological choices concerning the indicators' design, data use, scoring method and weight are shown. The ten major sustainability themes accomplish level 1 of the monitoring tool. This level applies to any agricultural sector. Because some of these themes are very broad, they were further subdivided (level 2). The themes and indicators at level 2 and level 3 specifically relate to the dairy sector, e.g. the indicators for animal health and welfare, although many of them are also valid for other agricultural sectors.

As stated before, some indicators receive a specific weight when they are considered more or less important than other indicators. This was the case for the indicators designed to evaluate a farm's 'productivity and efficiency' and for the indicators of 'soil quality'. For 'productivity and efficiency', we assigned half of the theme's weight to 'efficiency' and the other half to the partial productivity indicators, of which in turn 'labour productivity' takes 54%, 'capital productivity' 21% and 'land productivity' 25%. Those weights take into account production economic aspects, since they are based on the estimation of a Cobb-Douglas production function (Coelli et al., 1998) using a sample of dairy farms. Since the soil organic matter (OM) content highly influences the chemical, physical and biological quality of a soil (a.o. Davidson, 2000), it is considered to be a key-indicator of soil quality. We therefore assigned 'OM-content' half of the total weight of the theme 'soil quality'.

Table 5.1. Level 1, level 2 and level 3 themes and indicators of the monitoring tool, together with a concise definition and methodological choices

level 1	level 2	level 3	indicator definition	indicator design ^(a)	data type ^(b)	scoring method ^(c)	indicator weight ^(d)
ecological themes							
use of inputs	pesticides	<i>pesticide use^(e)</i>	<i>amount and environmental impact of used pesticides</i>				12.5
		pesticide management	risk of environmental impact from the application of pesticides, based on eight factors concerning pesticide management	l, e	ch	b	12.5
	energy	energy use efficiency	amount of product produced with one unit of energy	l	q	r	12.5
		renewable energy use	share of renewable energy sources used on the farm	e	q	s	12.5
	water	water use efficiency	amount of product produced with one unit of water	l	q	r	12.5
		alternative water resources use	share of alternative water resources (= rainwater, surface water and shallow ground water) used on the farm	e	q	r	12.5
	nutrients	nitrogen (N) surplus	risk of environmental impact from N use	l	q	s	6.25
		N use efficiency	amount of product produced per unit of N surplus	l	q	r	6.25
		phosphor (P) surplus	risk of environmental impact from P use	l	q	s	6.25
		P use efficiency	amount of product produced per unit of P surplus	l	q	r	6.25
quality of natural resources	soil quality	organic matter content	organic matter content of the soil	l	q	s	16.67
		pH	soil acidity as an indicator of chemical soil quality	l	q	s	1.85
		P content	P content of the soil as an indicator of chemical soil quality	l	q	s	1.85
		K content	K content of the soil as an indicator of chemical soil quality	l	q	s	1.85
		<i>biological soil quality</i>	<i>biological quality of the soil</i>				5.56
		<i>physical soil quality</i>	<i>physical quality of the soil</i>				5.56
	water quality		risk of surface water contamination from waste water, based on 3 aspects concerning waste water management	e	ch	b	33.33
	<i>air quality</i>		<i>risk of air pollution due to the farmer's agricultural activities</i>				33.33
biodiversity	<i>genetic diversity</i>		<i>diversity of crops and animals used in agriculture</i>				33.33
	<i>species diversity</i>		<i>diversity of wildlife species dependent or affected by agriculture</i>				33.33
	<i>habitat diversity</i>		<i>diversity of habitats related to agricultural production</i>				33.33

Table 5.1. Continued

level 1	level 2	level 3	indicator definition	indicator design ^(a)	data type ^(b)	scoring method ^(c)	indicator weight ^(d)
social themes							
internal social sustainability	professional pride		the emanation of how the farmer's identity and hence his expectations and aspirations fit with the daily reality of being a farmer in a constantly changing social, cultural, environmental, economic and political environment; assessment is based on the appreciation of eight factors (out of a list of 24) which the farmer considers as key for his own pride	f, e	qe	qe	33.33
	<i>decision latitude</i>		<i>the room for manoeuvre to take one's own decisions, according to one's own insights, capacities and desires</i>				33.33
	<i>care</i>		<i>the existence of formal and informal structures and institutions that allow people to take care of each other, according to their own values and norms</i>				33.33
external social sustainability	animal health and welfare	body condition score	percentage of thin cows	l, e	q	r	5.56
		dirtyness	share of dirty cows, based on the dirtyness of udders, flanks and legs	l, e	q	r	5.56
		skin lesions	share of cows with lesions on hocks, neck and spine	l, e	q	r	5.56
		locomotion score	share of cows with a low mean locomotion score	l, e	q	r	5.56
		teat-end condition	share of cows with thick and rough teat-end callosity rings	l, e	q	r	5.56
		udder condition	share of cows with subclinical and clinical mastitis	l, e	q	r	5.56
	landscape management	stewardship agreements	presence of stewardship agreements	e	qe	e	5.56
		small landscape	amount of time spent maintaining small landscape elements	e	qe	e	5.56
		nature conservation	efforts made for nature conservation	e	qe	e	5.56
		visual nuisance	efforts made to minimise visual nuisance	e	qe	e	5.56
		architectural quality	efforts made for architectural quality	e	qe	e	5.56
		surrounding landscape	awareness of the impact on the surrounding landscape	e	qe	e	5.56
	<i>social services</i>		<i>the provision of social services (e.g. green care)</i>				33.33
<i>disposable income</i>			<i>the total income (earned either at the farm or outside) that the farmer and his family have at their disposal</i>				100

Table 5.1. Continued

level 1	level 2	level 3	indicator definition	indicator design ^(a)	data type ^(b)	scoring method ^(c)	indicator weight ^(d)
economic themes							
productivity and efficiency	labor productivity		value added per unit of farm labour	l	q	r	27.0
	capital productivity		value added per unit of farm capital	l	q	r	10.5
	land productivity		value per unit of land use	l	q	r	12.5
	efficiency		ratio of actual total productivity to maximum attainable productivity	l	q	p	50
profitability	labor profitability		farm labour income per unit of farm labour	l	q	r	33.33
	return on equity		farm profit per unit of own capital	l	q	r	33.33
	return on assets		farm profit per unit of total capital (farm capital and land capital)	l	q	r	33.33
<i>risk</i>			<i>the probability that the production of value added is impacted by external events</i>				<i>100</i>
entrepreneurship			the extent of the farmer's entrepreneurship, based on three key-aspects of entrepreneurship: vision, strategy and management	l, e	qe	e	100

^(a) l=based on literature, e=based on experts opinion, f=based on new fundamental research

^(b) q=quantitative data, qe=questionnaire, ch=checklist

^(c) s=based on scientific knowledge or legislative standards, r=comparison to a reference group, b=based on Best Available Techniques (BAT), qe=based on a questionnaire, e=based on expert judgement, p=based on a production possibility curve

^(d) the weights sum up to 100 for each level 1 theme

^(e) italics indicate that the theme or indicator has not yet been fully detailed

As an example, we illustrate the applied methodology of indicator construction, data use, scoring and weighing, for the 'energy use efficiency' indicator of the case study farm:

- Indicator design: the choice of 'energy use efficiency' as a relevant indicator for 'energy use' and its calculation method were based on scientific knowledge retrieved from literature. A detailed description of the indicator and its calculation method is provided by Meul et al. (2007a; Chapter 3 in this thesis).
- Data use: the indicator calculation is based on quantitative data retrieved from the farm management account. The used amounts of direct farm inputs (diesel fuel, electricity and natural gas) and indirect farm inputs (mineral fertilisers, seeds, pesticides, concentrates, forages and machines) were converted into energy values using literature based conversion factors.
- Indicator calculation and scoring: Table 5.2 shows the calculation of the annual total energy use of the case study farm in 2003. Considering a milk production of 15,605 l ha⁻¹ this resulted in an energy use efficiency of 29 l milk 100MJ⁻¹. We defined benchmarks based on the indicator values of a reference group of comparable farms, in this case the specialized dairy farm data of the Flemish Farm Accountancy Data Network (FADN). The 10% best performing farms delimited the 100 score, the 10% lowest performing farms the 0 score. The indicator value of the case study farm was transferred into a score of 88, as shown in Figure 5.1.

Table 5.2. Annual total energy use of the case study dairy farm, data of 2003

Energy input	MJ ha ⁻¹
Direct energy input	
Diesel	7529
Lubricants	666
Electricity	4148
Other sources	1753
<i>Total</i>	<i>14096</i>
Indirect energy input	
Mineral fertiliser	5987
Seeds	457
Pesticides	393
Machinery	2221
Concentrates	30037
Forages	0*
<i>Total</i>	<i>39095</i>
Total energy input	53191

* No forages were purchased

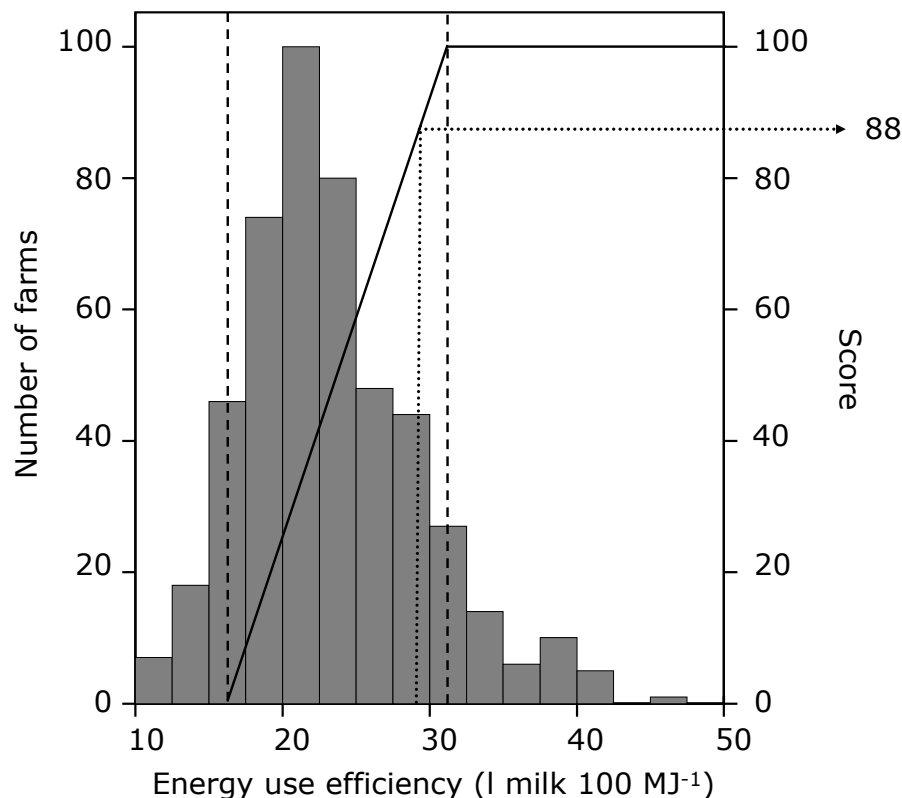


Figure 5.1. Histogram of the energy use efficiencies of the dairy farms of the Flemish Farm Accountancy Data Network (FADN) - data-entries of the years 1989, 1990, 2000 and 2001. Example of scoring the indicator for a single farm

- Indicator weighing: since there was no explicit evidence that the indicator 'energy use efficiency' is more or less important than the 'renewable energy use' to evaluate a farm's energy use, we gave both indicators the same weight. The weights in Table 5.1 take into account the assumption that the four aspects of the use of inputs (pesticides, energy, water and nutrients) are considered equally important.

For detailed information concerning the selection, design and calculation of other indicators of Table 5.1, we refer to the publications of Nevens et al. (2006), Meul et al. (2007b; Chapter 4 in this thesis), Goossens et al. (2007) and Steunpunt Duurzame Landbouw (2006).

5.3.3. The monitoring instrument: MOTIFS

We aggregated the scores of the different sustainability indicators into an integrated tool, which we named MOTIFS: MONitoring Tool for Integrated Farm Sustainability (Figure 5.2). MOTIFS allows for an immediate visual interpretation of a farm's sustainability for each of the ten major themes. The more a graph segment is filled with colour, the more a farm is considered sustainable for that specific theme.

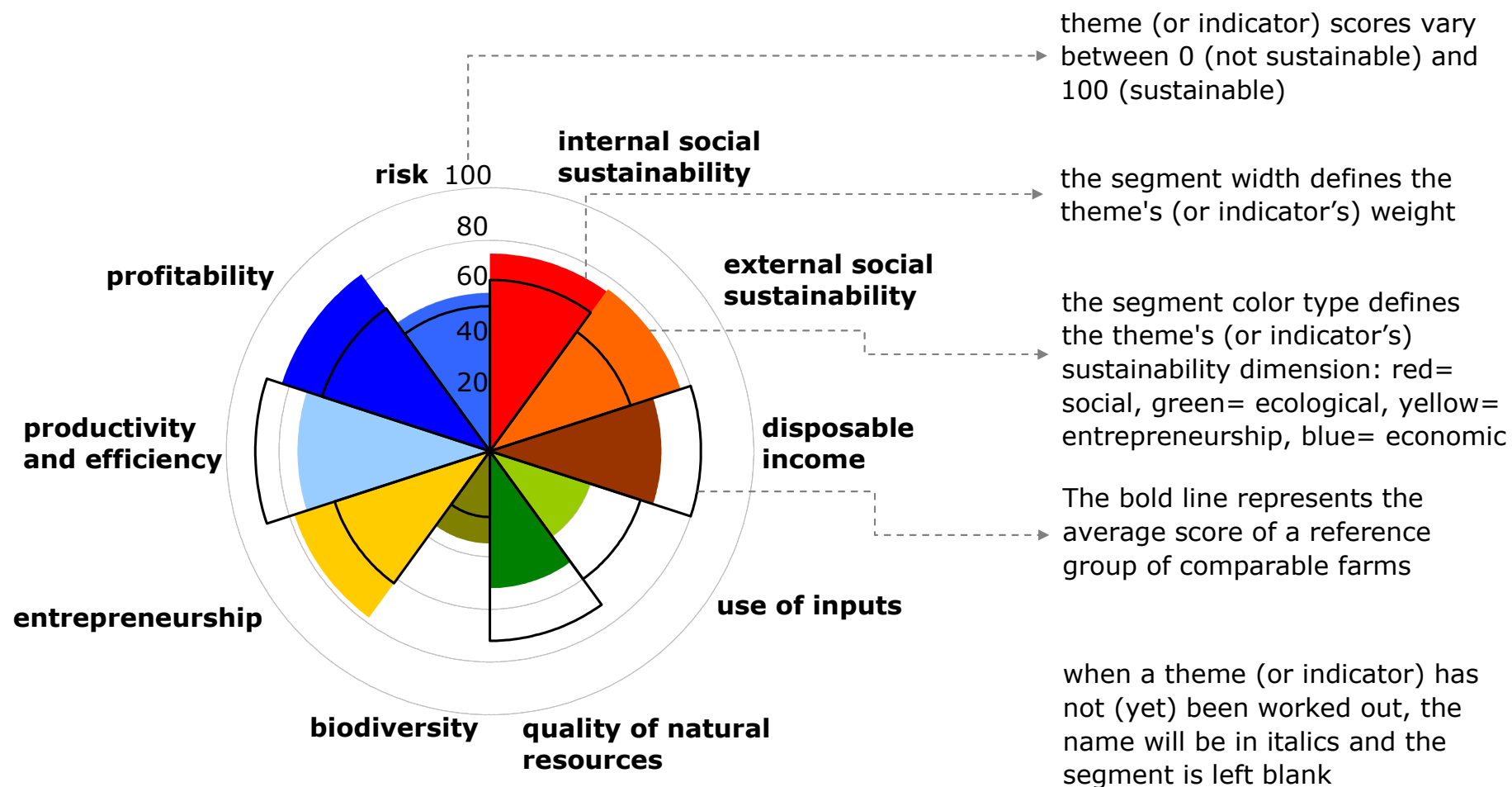
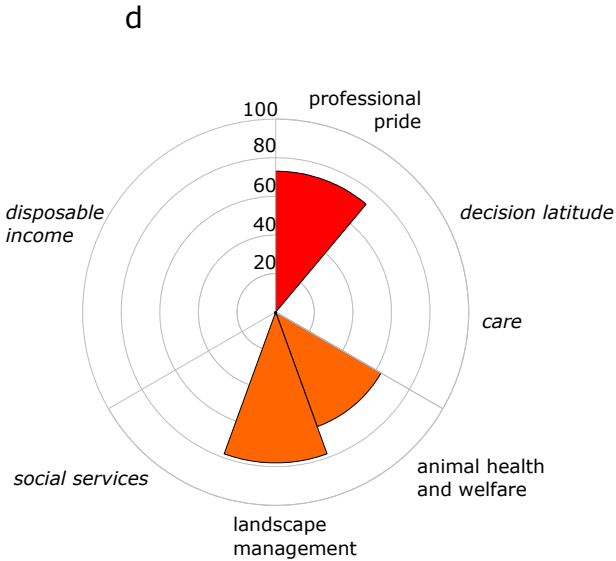
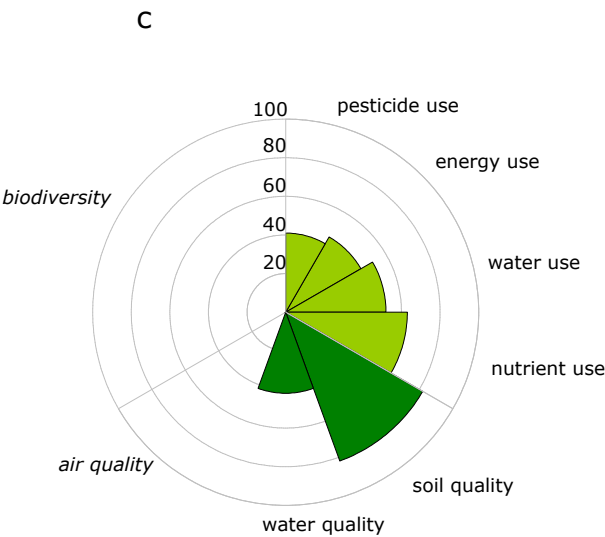
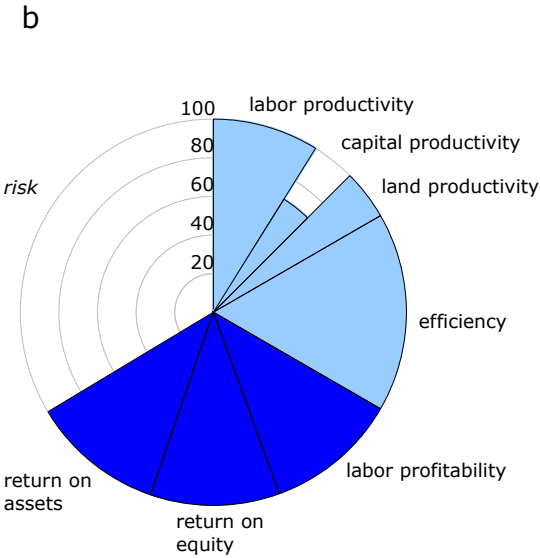
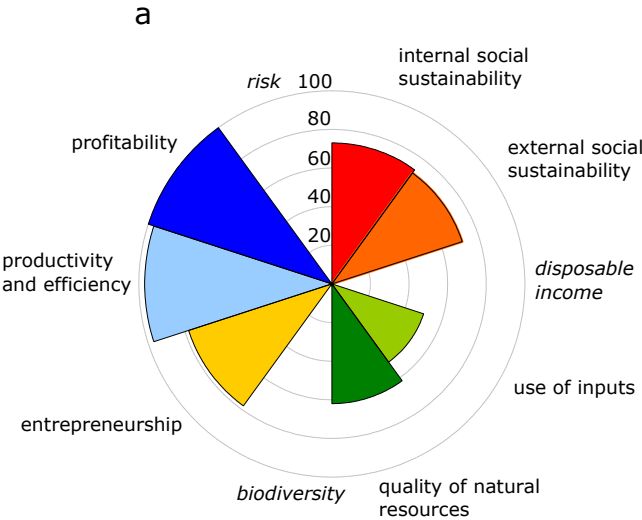


Figure 5.2. MOTIFS, level 1 graph and instructions on the reading and interpretation



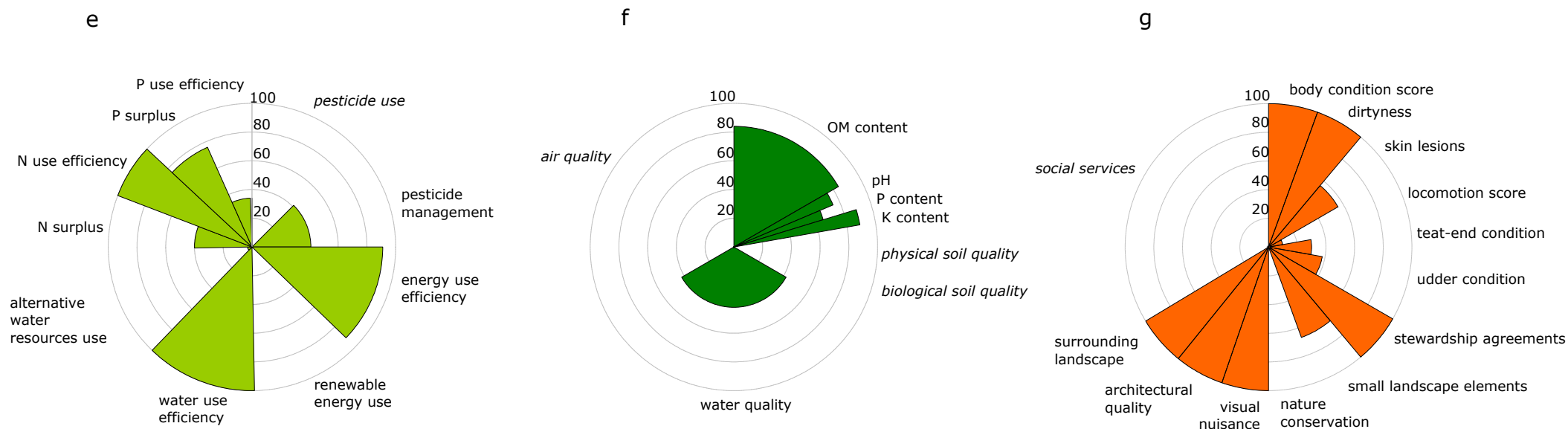


Figure 5.3. Results of the sustainability monitoring of the case study dairy farm: level 1 (a) gives an overview of the farm's integrated sustainability, level 2 gives an overview of the sustainability of the economic (b), ecological (c) and social (d) dimension and level 3 shows the indicator scores for the use of inputs (e), quality of natural resources (f) and external social sustainability (g)

The sustainability monitoring of the case study dairy farm is visualised in the radar graphs of Figure 5.3. The top graph (a) shows the overall sustainability of the farm, i.e. at the level of the ten major themes (level 1). The themes that were not yet measured are left blank. Starting from this level 1 graph, the farmer can zoom in on each of the three sustainability dimensions. The scores of their relevant themes and indicators are presented in an economic (b), an ecological (c) and a social (d) level 2 graph in Figure 5.3. At level 3, the indicator scores are visualised for a specific theme. In our case study, level 3 graphs were made for the use of inputs (e), quality of natural resources (f) and external social sustainability (g).

5.4. Discussion

5.4.1. Methodological issues

With the applied methodology, we tried to answer to some of the comments on existing monitoring tools, as formulated in the introduction part of this article: through the applied sequence of methodological steps – from vision over themes to indicators – we explained in detail how and why the considered themes and indicators were selected and we avoided using indicators that are not relevant for the problem at hand, or that are selected based on the availability of data rather than on scientific soundness and relevance. MOTIFS is also founded on the equality of the economic, ecological and social sustainability dimension and this equality is inherently built into the system.

In MOTIFS, all relevant sustainability themes are presented individually and each theme's score can be evaluated separately. Despite this individual presentation, there exists a link between different themes. This means that when a specific measure is taken to improve the sustainability of a specific theme (e.g. nutrient use), it can also induce an effect on other themes (e.g. energy use). Hence, MOTIFS allows a farmer to assess the effects of specific management measures on all relevant ecological, economic and social aspects of their business.

The applied methodology of indicator development fits within a content-based framework (von Wirén-Lehr, 2001; Van Passel, 2007), which provides specific indicators that characterize single parts of the system of concern (e.g. energy or nutrient use). Content-based frameworks facilitate the translation of principles into specific objectives and quantitative parameters, but sustainability assessment generally remains spatially limited – e.g. to the farm level – and temporally restricted – to one year in our study. An alternative framework for indicator development is a system-based framework, which provides indicators describing key attributes of systems as a whole, reflecting the condition of systems in a holistic and dynamic point of view. An example of a system-based

framework is provided by Bossel (2001). In this approach, the viability and performance of a farming system depends on the viability and performance of several subsystems, such as livestock, cropping and family subsystems. The farming system in turn contributes – together with other 'component systems' such as other farming systems, forest or water systems – to the viability and sustainability of a clearly defined larger system (e.g. a watershed region). In system-based frameworks, indicators reflect the viability of essential component systems as well as their contribution to the viability and performance of accompanying component systems and the larger system under study. The system-based approach seems particularly useful at larger geographical scales, for example to perform a sustainability evaluation of a specific region.

5.4.2. Stakeholder participation

Stakeholder participation and expert consulting took an important place in the development of MOTIFS (described in more detail in Chapter 6 of this thesis). This approach has been found very successful for developing sustainability indicators (van Calker et al., 2005). Moreover, discussions among stakeholders - based on scientific information - may themselves contribute to the development of sustainable farming systems (Rossing et al., 1997). According to Oels (2003), dialogue between stakeholders and actors at all levels is essential to translate shared understandings and interpretations into collective action on sustainable development.

Bossel (2001) considers the participative process of indicator development an essential aspect of system-based frameworks. However we think this also holds for the methodology we followed to develop MOTIFS: the different steps (from vision to themes to indicators) require a large number of choices that reflect the knowledge and values of those who develop the indicators. It is therefore essential to bring in a wide spectrum of knowledge, experience, mental models, and social and environmental concerns to ensure that a proper indicator set is found (Bossel, 2001). This participatory approach is essential to ensure that the developed set of indicators encompasses the visions and values of the community or region for which it is developed (Bossel, 1999).

A broad participation is also considered an important guideline within the Bellagio Principles⁶ (Hardi and Zdan, 1997). These principles describe some major guidelines for practical assessment of progress towards sustainable development. According to these guidelines, assessment of progress toward sustainable development should be guided by a clear vision of sustainable development and

⁶ The Bellagio Principles were developed by an international group of researchers and practitioners during a meeting held in November 1996, at Bellagio, Italy

goals that define that vision. The indicators should reflect a holistic view of the linkages between the social, environmental and economic aspects, they should consider the essential elements (equity and disparity, economic development, ecological conditions) and they should have the adequate scope while still offering a practical application. The process of developing indicators should be open and inclusive with an effective communication and a broad participation. Finally, an ongoing assessment of the quality of the indicators should be conducted.

MOTIFS and its development procedure highly comply with the guidelines for indicator development according to the Bellagio Principles: indicator development started from a vision on sustainable agriculture, which was translated in principles and themes. MOTIFS reflects a holistic view of economic, ecological and social aspects. MOTIFS is designed to support an effective communication about sustainability and through the stakeholder participation, the development process was open with a broad participation. Considering the practical application of the tool and the assessment of the quality of the indicators, we developed and applied an extensive validation procedure, which is discussed in Chapter 6 of this thesis.

5.4.3. Practical application of MOTIFS

We encourage the application of MOTIFS on farms in practice, even though not all indicators have been worked out yet in detail, for a number of reasons:

- Even though some of them have not been worked out yet at farm level, by explicitly including these themes and indicators into the tool (Table 5.1, in italics), it is emphasized that the list of indicators that can already be used is not limitative, and that the result is not yet a complete monitoring of a farm's overall sustainability. Moreover, when the farmer is aware of some data gaps to calculate indicators, he might be stimulated to collect these farm data that are needed for the sustainability evaluation.
- Application of the monitoring tool in practice is necessary to be able to perform a sound end-use validation.
- Since 'sustainability' is not a static concept, but characterises a constant evolution, a monitoring tool to evaluate sustainability will never be 'finished'. Themes, indicators and benchmarks - and consequently also the monitoring tool - will continuously be subjected to change. We anticipated on that possible change by developing a flexible tool in which it is easy to add or remove themes and indicators, or to change benchmarks, but that also fits well within a sound theoretical frame of vision - principles - themes - indicators.

MOTIFS can be a promising integrated tool to guide (dairy) farmers' management towards a higher level of sustainability. The visual integration of relevant themes of ecological, economic and social sustainability aspects and sustainable entrepreneurship allows an immediate and integrated interpretation of a farm's overall sustainability level and gives an overview of the farm's strengths and weaknesses. Taking into account the pre-defined indicator quality criteria of causality, sensitivity, solidness, comprehensibility and the use of benchmarks, we developed a set of indicators that can be used as a complete and relevant decision aid tool for farmers. Apart from that, the specific attention we gave to aspects of communication and user-friendliness resulted in a monitoring tool that seems particularly interesting for use in discussion groups of farmers to mutually compare results and exchange knowledge and expertise. Moreover, by using the monitoring tool to compare farm performances of an individual farm over time, the farmer can follow up whether management actions actually result in the desired effect. This can make MOTIFS a useful management tool.

Introducing the tool to farmers appears realistic and promising, since farmers' organisations have already shown interest in applying the tool in practice on Flemish farms. For the moment, MOTIFS is being used on 20 Flemish dairy farms participating in a Leader+ project (European Commission, 2007b). During the period 2006-2008, a project leader visits the farmers, collects farm data, calculates indicators and makes radar graphs with the results of each farm. Those results are then presented in a discussion group where the farmers can compare the weak and strong aspects of their farms and discuss possible actions to be taken. This practical application functions as an end-use validation of MOTIFS, since feedback is received from the farmers on the practical use, data collection, invested time and costs, allowing an optimisation of the indicators and of the tool as a whole.

However, work should still be made of some important unfinished aspects of MOTIFS. First of all, all themes and indicators (as summarized in Table 5.1) should be worked out in detail. Secondly, to translate the theoretical outcome of MOTIFS into agricultural practice, management advice and guidance is needed. To a certain level, the farmers can develop appropriate management strategies by themselves, considering their own priorities and conditions and based on the provided indicator descriptions or calculation methods. However, to enhance a successful implementation and hence guide farmers' actions towards a higher level of sustainability, case- and site-specific advice should be provided (von Wirén-Lehr, 2001). This could possibly be fulfilled by farm advisors, who are highly qualified to discuss the different sustainability aspects in confidence with the farmers and to provide additional information and advice that is essential to decide on appropriate measures and to take actual actions.

Finally, although we believe that MOTIFS can guide farmers to take the proper actions towards more sustainable agricultural systems, we think that in truly sustainable systems, unsustainable (economic, ecological or social) situations or impacts should not only be reduced, but radically eliminated. Therefore, totally new production systems should be considered and/or designed. This is a long-term process. In such a context of transition towards future (agricultural) production, optimisation of current systems is a first step to translate 'sustainability' into concrete actions. MOTIFS is considered a suitable guide in this optimisation effort, but one should be aware of the potential danger to lock even optimised systems into suboptimal future development paths.

5.5. Conclusions

In this paper we proposed a methodological framework for developing MOTIFS, a monitoring tool to guide Flemish (dairy) farms towards a higher sustainability level, and we illustrated its practical use on a specific Flemish dairy farm as a case study. The methodology consisted of four successive steps:

- translating the major principles of a supported vision on sustainable Flemish agriculture into concrete and relevant themes;
- designing indicators to monitor progress towards sustainability for each of those themes;
- aggregating the indicators into an integrated farm sustainability monitoring tool;
- applying the monitoring tool on a practical farm, as a first end-use validation.

Stakeholder participation and expert consulting took an important place in each of these methodological steps.

As a result, we developed a user-friendly and strongly communicative instrument to measure progress towards integrated sustainable dairy farming systems. MOTIFS is founded on the equality of the economic, ecological and social sustainability dimension and this equality is inherently built into the system. The tool fits within a well founded methodological framework and is based on a set of relevant indicators.

Through the applied methodology, we avoided using indicators that are not relevant for the problem at hand, or that are selected based on the availability of data rather than on scientific soundness and relevance.

In our opinion, the end-use validation of the tool is of critical importance to its optimization and continuous improvement. For that reason we encourage its application on as many practical Flemish farms as possible, even though at this stage not all indicators have been worked out in detail.

Chapter 6

Validation of MOTIFS and suggestions for its effective application in practice



Redrafted after:

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Abstract

Although many indicator-based sustainability monitoring tools for agriculture have been developed in the last decade, considerably less effort has been put on their validation. In the present study we developed and applied a procedure to validate (i) MOTIFS, an indicator-based monitoring tool for integrated farm sustainability of Flemish dairy farms and (ii) a selection of ecological indicators (included in MOTIFS), related to nutrient use, energy use, water use and water quality. The procedure considers two steps. The first step is an accuracy evaluation, which consists of a design validation related to the scientific quality of MOTIFS and its selected indicators, and an output validation that is an evaluation of the information supplied by their output. For both validation types, we applied a transdisciplinary approach of stakeholder participation. The second step is a credibility evaluation, which relates to the degree of confidence potential end-users have in MOTIFS and hence their willingness to effectively use it in practice. This involves an end-use validation, for which we designed a test to evaluate (i) the end-use value of the selected indicators as decision aid tools, (ii) the end-use value of MOTIFS as a decision aid tool and communication tool and (iii) the willingness of potential end-users to use MOTIFS in practice. We considered two potential end-user groups: Flemish dairy farmers and 'sustainability consultants' (e.g. agricultural advisors assigned by farmer's organisations). Based on the validation results, we made suggestions to improve the tool and its effective application in practice. We concluded that MOTIFS is a potentially effective sustainability monitoring *and* management tool, since it has major assets that should be incorporated in any indicator-based system: positioning, informing, learning and communicating.

Keywords: Accuracy, Credibility, Indicators, Sustainability, Validation

Validation of MOTIFS and suggestions for its effective application in practice

6.1. Introduction

Indicator-based monitoring tools are frequently applied as effective tools for sustainability assessments (Bell and Morse, 1999; Bossel, 1999). Also for agriculture, indicator-based farm monitoring tools have been developed and are used in practice. Some of them are 'visual integration' tools, aggregating scores of a balanced set of relevant sustainability indicators into radar graphs (Bockstaller et al., 1997; Rigby et al., 2001) or bar graphs (Lewis and Bardon, 1998); others are 'numerical integration' tools, aggregating indicator values into a single composite index (e.g. Taylor et al, 1993; Van Passel et al., 2007).

Despite the extended interest in the development and use of indicators and indicator-based assessment tools, considerably less effort goes to their validation (Rigby et al., 2001). This in spite of earlier urgent calls to develop distinctive criteria to evaluate the success in construction and use of decision support systems in agricultural management (Cox, 1996).

In general, validation checks the extent to which a developed instrument or solution meets the anticipated criteria. Validations are often associated with (mathematical) models since they are considered key aspects in any model development process (a.o. Sargent, 1999). If a model aims to answer multiple questions, the validity of the model should be determined with respect to each of those questions (Sargent, 1999). Thereby, validation verifies whether a model possesses a satisfactory degree of 'accuracy' consistent with its intended application. Another asset of an effective model is its 'credibility', expressing the potential users' confidence in a model and the information derived from it, and hence their willingness to effectively use it.

When we translate this experience of model validation to indicator validation, we obtain a framework considering two aspects: an evaluation of the indicator's accuracy and an evaluation of its credibility. Hereby, accuracy evaluation relates to the degree of correctness of an indicator with regard to its intended application, i.e. the degree to which the indicator reaches its intended goals. Considering an indicator's accuracy, two validation aspects can be considered, as defined by Bockstaller and Girardin (2003): 'design validation' evaluates the

scientific quality of the indicator construction or design and 'output validation' checks the information that is supplied by the indicator output.

An indicator's credibility requires an evaluation of the indicator's end-use value – i.e. its usefulness to potential end-users, referred to as 'end-use validation' (Bockstaller and Girardin, 2003) – and an evaluation of the willingness of potential end-users to effectively use it in practice.

The aim of the study at issue is to validate an indicator-based sustainability monitoring tool, considering the methodological framework of indicator validation described above. Therefore, we have three main objectives:

- to develop a detailed validation procedure to evaluate the accuracy and credibility of indicator-based sustainability monitoring tools;
- to apply this procedure to validate MOTIFS, a specific indicator-based monitoring tool for sustainability of Flemish dairy farms;
- to make suggestions for improving the accuracy and credibility of MOTIFS, based on the validation results.

6.2. Materials and methods

6.2.1. MOTIFS

MOTIFS is an indicator-based sustainability monitoring tool for Flemish dairy farms. It allows us to monitor farm progress towards integrated sustainability, i.e. taking into account economic, ecological as well as social aspects, using a set of relevant indicators. The tool offers a visual aggregation of indicator scores into an adapted radar graph, considering ten sustainability themes related to ecological, economic and social aspects. A detailed description of MOTIFS and its underlying methodology is provided by Meul et al. (2008; Chapter 5 in this thesis).

6.2.2. Practical application of MOTIFS at a pilot group of Flemish dairy farms

A selection of sustainability themes extracted from MOTIFS was applied to 20 dairy farms, located in the North-Western part of Flanders, to monitor sustainability and stimulate communication and exchange of knowledge between farmers. These 20 farms participate in a Leader+ project called 'Sterk met Melk (Strong with milk, 2006-2008)'. Leader+ ('Liaisons Entre Actions de Développement de l'Economie Rurale') is an initiative financed by EU structural

funds and is designed to help rural actors consider the long-term potential of their local region (European Commission, 2007b).

With an average of 56 cows, a milk production of 8381 l cow⁻¹ year⁻¹ and a total usable area of 48 ha, the participating farms are considered rather large farms according to Flemish standards.

A project leader visits each farm every three months and collects data, calculates indicators and discusses the results with each farmer individually. In addition, she organises communication sessions for the whole group of participating farmers, in which they can discuss their results for a specific sustainability theme with the project leader and an invited expert. A bi-annual meeting of the project's steering committee – consisting of representatives of farmer's organisations, agricultural research institutes and local policymakers – advises on the methodological and structural aspects of the project.

During the first period (2006-2007), the project has focused on aspects of ecological sustainability: nutrient use, energy use, water use and water quality. However, besides these ecological themes, also economic and social aspects will be dealt with during 2008.

Considering the objectives of the present study, we use the selection of ecological sustainability indicators already measured on the 20 participating farms to develop and apply the validation procedure. In the following, we briefly describe the considered indicators.

6.2.3. Selected ecological sustainability indicators

6.2.3.1. Nutrient use

Nutrient use is evaluated by two indicators: N surplus and N use efficiency. The N surplus is calculated as total N input – total N output. N inputs on a Flemish dairy farm comprise N in purchased concentrates, forages and by-products, straw (or sawdust), animals, mineral fertiliser and manure, in biological fixation and in atmospheric deposition. N outputs are comprised in exported milk, animals, manure and crops. All inputs and outputs are expressed in kg N per ha of total utilised farm area. We define N use efficiency as the ratio between the farm's main product output (litres of produced milk) and the N surplus (kg N), according to the principle of eco-efficiency: adding maximum value with minimum use of resources and with minimum environmental impact (WBCSD, 2000). A detailed description of these indicators, their calculation method and application results on a representative set of Flemish dairy farms is provided by Nevens et al. (2006).

6.2.3.2. Energy use

We consider two indicators to evaluate the energy use at Flemish dairy farms: energy use efficiency and use of renewable energy. Energy use efficiency is expressed as the amount of product produced with one unit of energy, according to the above-mentioned principle of eco-efficiency. For dairy farms, this indicator is calculated as the ratio of the amount of produced milk (litre) to the total energy input (MJ). Hereby, total energy input consists of direct and indirect energy inputs. Direct energy is used on farm for agricultural activities and it comprises mainly diesel fuel, electricity and natural gas. The energy that is used to produce farm inputs such as mineral fertilisers, seeds, pesticides, concentrates, forages and machines is indirect energy. A detailed description of this indicator, its calculation method and application results on a representative set of Flemish dairy farms is provided by Meul et al. (2007a; Chapter 3 in this thesis). The use of renewable energy is expressed as the share (%) of renewable energy sources that are used on the farm in the overall direct energy use. The indicator is calculated by dividing the amount of renewable energy used on the farm (MJ) by the overall direct energy use (MJ), multiplied by 100.

6.2.3.3. Water use

Persistent excessive use of deep groundwater results in a constantly decreasing natural groundwater table in several regions in Flanders (Van Damme and Nechelpuut, 2005). This not only leads to a possible shortage of groundwater in the future, it can also negatively influence the groundwater quality. Lower crop yields, higher costs to acquire water of high quality and loss of biodiversity are only a few possible negative impacts (Van Damme et al., 2004). Comparable to energy use, we consider two indicators to evaluate the water use on Flemish dairy farms: water use efficiency and use of alternative water resources.

Water use efficiency is calculated as the ratio between the amount of produced milk (litre) and the total amount of water used on the farm (m^3). This indicator was also used by Zhen et al. (2005) to evaluate the water management of farms, and again complies with the principle of eco-efficiency. On Flemish dairy farms, total water use consists of (i) drinking water for dairy cows and heifers, (ii) cleaning water for stables, calf pens, milking parlor, udders, milk tank, milking machinery and field machinery, (iii) water used in a plate cooler and (iv) water for a walk-through foot-bath for the cows. Generally, irrigation of fodder crops is not applied in Flanders.

The second indicator, the use of alternative water resources, assesses the farmer's management efforts to use rainwater, surface water or shallow groundwater as alternatives to deep groundwater and drinking water (usually retrieved from purified deep groundwater). The indicator is calculated as a

weighted average of the shares of rainwater (%RW), surface water (%SW) and shallow groundwater (%SGW) within the farm's total water use: use of alternative water resources = $0.44 \%RW + 0.34 \%SW + 0.22 \%SGW$. The weights are based on experts' opinion and pragmatically indicate the presumed relative importance of rainwater, surface water and shallow groundwater as alternative water resources.

6.2.3.4. Water quality

The main sources of water pollution from agricultural activities relate to contamination with nutrients, pesticides, heavy metals, soil sediments, organic matter, acid substances, biological contaminants and mineral salts (OECD, 2001). Since monitoring the water quality is often costly and difficult, we propose to use indicators that estimate the risk of water contamination originating from agricultural activities. The risk of diffuse water pollution through run-off and losses of contaminants is incorporated in the indicators developed to evaluate related sustainability themes, such as the use of nutrients and pesticides and soil quality.

However, an additional potential risk of water pollution comes from the disposal of a farm's wastewater. Therefore, we use an indicator related to wastewater management to evaluate the water quality. Hereby, an indicator score is based on the comparison of the wastewater management techniques that are actually applied on the farm to the (combinable) alternatives as defined by the Best Available Techniques (BAT, Derden et al., 2006). Each indicator score varies between 0 and 100, as determined by experts. The different techniques for wastewater management at Flemish dairy farms and their related scores are summarised in Table 6.1. The indicator score is calculated as the average of the scores for each of the three considered types of wastewater: (i) wastewater from cleaning milking machinery and milk tank, (ii) wastewater contaminated with manure and (iii) silage leachate and run-off from bunker silos.

Table 6.1. Techniques of wastewater management on Flemish dairy farms, and their related scores

Type of wastewater	Score
Wastewater from cleaning milking machinery and milk tank	
- direct drainage into the public sewer system	100
- drainage into the manure cellar	100
- drainage into surface water after treatment with an on-farm water-treatment system	100
- direct drainage into surface water without treatment	0
Wastewater contaminated with manure (e.g. cleaning water from milking parlor, calf pens, stables)	
- drainage into the manure cellar	100
- any other alternative	0
Silage leachate and run-off from bunker silos	
- taking measures to limit silage leaching and run-off ^(a)	
- and using a first-flush system ^(b) with irrigation of second fraction run-off	100
- and using a first-flush system with infiltration of second fraction run-off	75
- and using a first-flush system with direct drainage of second fraction run-off into the surface water	50
- and direct drainage into the surface water without using a first-flush system	25
- taking no measures to limit silage leaching and run-off and direct drainage into the surface water without using a first-flush system	0

^(a) Leaching and run-off from a bunker silo can be limited by e.g. harvesting forage with high dry matter content (>27%), ensiling under dry weather conditions, frequently dry-cleaning the silo or carefully covering it after each use.

^(b) First flush is the first, often highly contaminated run-off fraction during the early stages of a heavy rainfall, due to the washing effect of runoff on pollutants. The first flush can be separated from the second, more diluted run-off fraction through the use of a first-flush system, which collects the first flush into a separate tank or into the manure cellar.

6.2.4. Validation processes

Considering the validation framework described in the introduction part of this paper, an indicator-based sustainability monitoring tool is validated on its accuracy and on its credibility. This validation procedure can be applied at the level of (a selection of) sustainability indicators that build up the monitoring tool as well as on the level of the tool as a whole. In the following, we discuss these different validation aspects in greater detail.

6.2.4.1. Accuracy evaluation

According to the International Institute for Sustainable Development (Bossel, 1999), “an indicator quantifies and simplifies phenomena and complex realities to a manageable amount of meaningful information, feeding decisions and directing actions”. This is the indicator’s intended application. The indicator’s accuracy relates to the degree to which it is consistent with its intended application.

The accuracy evaluation of an indicator-based monitoring tool as a whole takes into account its specific intended applications. Since MOTIFS was designed as a decision aid tool for farmers to guide farm management towards higher sustainability and as a communication tool for farmers to compare results and exchange knowledge and expertise (Meul et al., 2008; Chapter 5 in this thesis), both aspects are taken into account in the accuracy evaluation.

Considering the methodological framework for indicator validation of Bockstaller and Girardin (2003), the accuracy evaluation comprises two aspects: a design validation and an output validation.

Design validation is used to evaluate whether an indicator is scientifically founded and can be carried out by submitting the design or construction of an indicator to a panel of experts. This corresponds to the ‘independent verification and validation approach’ of models (Sargent, 1999), where an independent party – i.e. independent of both the model developers and the model users – decides whether a model is valid. Another option is to use expert judgements during the design of the indicators (a priori validation).

The main concern of output validation is to assess the soundness of the indicator output. Ideally, a comparison can be made of indicator outputs with measured field data, as proposed in model validation. However, since indicators are generally not used to predict an actual impact but to supply information about a potential impact, a linear relation between indicator output and field data cannot be expected (Bockstaller and Girardin, 2003). Furthermore, in the case of sustainability indicators, direct comparison with measured data is a priori

impossible because of the impossibility of measuring sustainability. Therefore, other procedures are suggested. One option is to compare the indicator output with the output of other indicators that have the same purpose, but that are constructed in a different way. Another option is to compare the indicator output with values given by experts. A last possibility is to submit the indicator output to a panel of experts (for example a group of farmers) that evaluates its relevance and reliability.

We used a transdisciplinary approach of expert and stakeholder participation (Thompson Klein et al., 2001; Astleithner and Hamedinger, 2003) to carry out the design and output validation of MOTIFS and the selected ecological indicators:

- For each indicator, feedback groups of experts and stakeholders discussed the (perceived) relevance and underlying methodological choices such as indicator design, data use, choice of benchmarks and weight. Generally, 10 to 20 experts and stakeholders – representatives of research organisations, policies, farmer organisations, ... – were brought together as a feedback group of a specific sustainability theme, e.g. energy use. These meetings were organised for every theme and they typically lasted half a day. After a detailed presentation of the proposed indicators and underlying methodology, specific questions were asked to the feedback group, concerning the indicators' methodological choices. Based on the group's remarks and discussions, possible adjustments to the indicators were made. This method was also used to validate the design of MOTIFS: a feedback group discussed the methodological choices concerning indicator aggregation (e.g. visual versus numerical) and aspects of design (e.g. adapted radar graph versus bar graph).
- We consulted experts to select and design relevant indicators for water use and water quality, since little information was found on indicators for sustainable water management at non-irrigated dairy farms (e.g. Zhen et al, 2005). Several Flemish agricultural research centres have considerable experience on water management at Flemish farms (e.g. POVLT, 2007; PCG, 2007; PCS, 2007). Besides, extensive expertise concerning water use and management is available at the Flemish Environment Agency (VMM, 2007). Therefore, experts of these institutes were consulted during the design of the indicators for water use and water quality. Meetings with a limited group of 4 experts were organised on a regular basis to choose and develop the relevant indicators, to select benchmarks and discuss practical problems concerning data use. Finally, the resulting indicators and underlying methodologies were presented to a larger feedback group of experts. This approach has previously proved to be a successful method for assessing the relevant indicators of ecological, economic and social sustainability (van Calster et al., 2005).

In addition, we validated the scientific quality of MOTIFS and its sustainability indicators by compiling existing scientific knowledge from scientific publications and by publishing our methodologies and results in peer-reviewed scientific journals. The publications of Nevens et al. (2006) and Meul et al. (2007a, b; Chapters 3 and 4 in this thesis) validate the scientific design of the indicators for nutrient use and energy use. Accordingly, the publication of Meul et al. (2008; Chapter 5 in this thesis) validates the scientific quality of MOTIFS as an integrated indicator-based monitoring tool for farm sustainability.

6.2.4.2. Credibility evaluation

An indicator's credibility evaluation relates to the degree of confidence potential end-users have in the indicator, and hence their willingness to effectively use it in practice. This involves an end-use validation (Bockstaller and Girardin, 2003), assessing the indicator's end-use value. Perhaps the most important asset of a (sustainability) indicator is its potential to trigger action, which determines its end-use value. The end-use validation of MOTIFS relates to the end-use value of the tool to make sustainability concrete, to guide farm management towards higher sustainability and its end-use value as an effective communication tool.

According to Girardin et al. (1999), a decision aid tool can mainly be tested by the quality of the support which it provides. This may be characterized through a survey in which the potential users can point out the strengths and weaknesses of the indicators. Such a survey can also be helpful to ensure that end-users understand what is being indicated and to check whether the results are interpreted correctly.

We designed a test that allows for an evaluation of the end-use value of MOTIFS and its selected indicators, combined with an evaluation of the willingness of potential end-users to effectively use MOTIFS in practice. Hereby, we considered two potential end-user groups: Flemish dairy farmers and 'sustainability consultants' (e.g. agricultural advisors assigned by farmer organisations). Both potential end-user groups are represented in the Leader+ project 'Sterk met melk', where the participating farmers and the members of the steering committee are considered representatives of the respective potential end-user groups 'farmers' and 'sustainability consultants'.

Table 6.2. Relevant topics and some example questions, prepared as a guide to interview the potential end-users of MOTIFS and its selected indicators

	Indicators for the selected ecological sustainability themes: nutrient use, energy use, water use and water quality	MOTIFS, as an integrated monitoring tool
End-use value as a decision aid tool	Do you find the indicators useful tools to advise on how to make farm management more sustainable? Why/why not?	Do you find MOTIFS useful to advise on making farm management more sustainable? Why/why not?
End-use value as a communication tool		Do you find MOTIFS useful to communicate about sustainability? Why/why not? What is, in your opinion, the best way to organise communication about sustainability with and between farmers (individual discussions, group discussions...)?
General support base and additional remarks	Do you agree on the selected themes of ecological sustainability? Why/why not? Do you agree on the selected indicators for each theme? Why/why not? Do you agree on the calculation method of the indicators? Why/why not? Do you agree on the minimum and maximum reference values for scoring? Why/why not? Does the collection of data to calculate the indicators entail extra costs and/or efforts?	Do you find it useful to aggregate different aspects of sustainability into a graphic tool? Why/why not? Do you have any remarks on the design of MOTIFS? Does MOTIFS have an added value compared to the management advice farmers already receive from specialists? Why/why not? Would you find it useful to discuss the results of MOTIFS on a regular basis during meetings between agricultural advisors and farmers on how to optimise farm management?

Due to the explorative nature of the test, a qualitative research approach was the obvious choice. Qualitative research methods were developed in the social sciences to enable researchers to study social and cultural phenomena. Examples of qualitative methods are action research, case study research and ethnography. Qualitative data sources include observation and participant observation (fieldwork), interviews and questionnaires, documents and texts, and the researcher's impressions and reactions (Myers, 2007).

For the specific purpose of the end-use validation, semi-structured interviews are adequate tools. Qualitative research interviews aim to investigate and understand a situation or a problem from the subject's point of view, unfolding the meaning of peoples' experiences and uncovering their lived world prior to scientific explanations (Kvale, 1996). More specifically, semi-structured interviews are used to obtain specific information from a sample of a population, to obtain general information relevant to specific issues and to gain a range of insights on specific issues (FAO, 1990). This type of interviews is also useful when the scope of the research is the understanding of an individual or group perspective (Fontana and Frey, 2000). Semi-structured interviews allow for focused, conversational, two-way communication. They can be used both to give and to receive information.

Semi-structured interviewing is guided only in the sense that some form of interview guide is prepared beforehand, which provides a framework for the interview. Relevant topics are initially identified and these topics form the basis for more specific questions which do not need to be prepared in advance. The majority of questions are created during the interview, allowing both the interviewer and the person being interviewed the flexibility to probe for details or discuss issues (FAO, 1990).

Table 6.2 is a matrix of relevant topics and some example questions that were prepared as a guide for interviewing the potential end-users of MOTIFS, taking into account the objectives of the end-use validation mentioned above. Besides the topics of Table 6.2, we also captured the support base for the concept of sustainability itself, by asking the potential end-users' opinion on the importance of communicating about sustainability and of striving for a more sustainable farm management.

Eight members of the steering committee (including the project leader) of the project 'Sterk met melk' were interviewed individually, while eight participating farmers joined in a group interview. The latter was conducted during a communication session between the farmers. During each of the interviews brief notes were taken, that were elaborated immediately after the interview.

The data analysis consisted of sorting the responses to the questions into three preset categories (Taylor-Powell and Renner, 2003), expressing the respective fields of interest of the end-use validation: (i) end-use value of the selected indicators as decision aid tools, (ii) end-use value of MOTIFS as a decision aid tool and communication tool and (iii) willingness to use MOTIFS in practice. For each category, we summarized the responses of the two potential end-user groups and singled out specific interesting remarks. Based on this analysis, we proposed some suggestions for improving the end-use value of the indicators and MOTIFS and for enhancing their practical application.

6.3. Results and discussion

6.3.1. Ecological sustainability indicators of the pilot group of Flemish dairy farms

Table 6.3 presents the average values of the ecological indicators measured at the 20 participating dairy farms of the project 'Sterk met Melk'. The indicator values show that, on average, the 20 pilot farms perform well on the use of nutrients and energy, compared to a representative group of Flemish specialised dairy farms (data of 2000-2001) with an average N surplus of 250 kg ha⁻¹, an average N use efficiency of 40 l milk kg⁻¹ N surplus and an average energy use efficiency of 27 l milk 100MJ⁻¹ (Meul et al., 2007b; Chapter 4, p.60-62). Renewable energy is not used on any of the 20 pilot farms, while the use of alternative water resources varies considerably between the farms.

Table 6.3. Average, 10th percentile (P10) and 90th percentile (P90) values of the measured ecological indicators at the 20 participating farms of the 'Sterk met Melk' project

Indicators	Average	P10	P90
Use of nutrients			
N surplus (kg N ha ⁻¹)	222	104	298
N use efficiency (l milk kg ⁻¹ N surplus)	59	34	100
Energy use			
Energy use efficiency (l milk 100MJ ⁻¹)	34	30	43
Renewable energy use (%)	0	0	0
Water use			
Water use efficiency (l milk m ⁻³ water)	242	201	297
Alternative water resources use (%)	22	0	72
Water quality			
Average score	66	44	97

For the indicators on energy and water use and for the N use efficiency, the 10th and 90th percentiles – the 2 best performing and 2 lowest performing farms - (Table 6.3) were used as respective minimum (B_{\min}) and maximum (B_{\max}) benchmark values to rescale indicator values into scores between 0 (indicating a worst-case situation) and 100 (indicating assumed sustainability). This rescaling allows a mutual comparison of the different indicators. For N surplus, B_{\max} was set at 150 kg N ha⁻¹, which is assumed to be compliant with the European Nitrates Directive on soil water protection (Nevens et al., 2006).

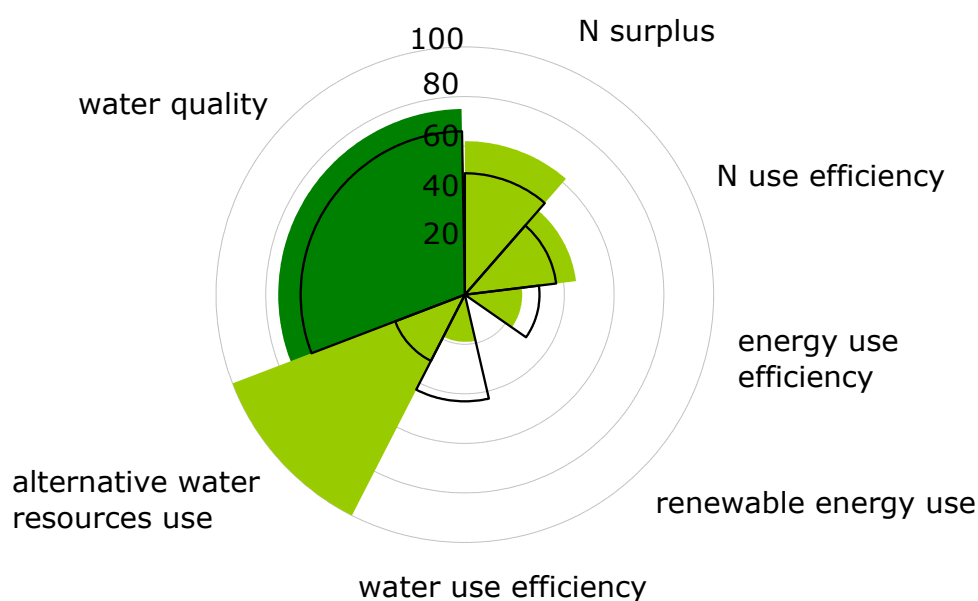


Figure 6.1. Adapted radar graph of ecological indicator scores, results of a Flemish dairy farm participating in 'Sterk met Melk'

For each farm, all indicator scores were aggregated into an adapted radar graph of ecological sustainability; an example of a specific farm result is shown in Figure 6.1. Such graphs are used as starting points in the discussion sessions, in which the farmers, together with the project leader and an invited expert, discuss their results and management practices that influence the different farm results. In the example graph (Figure 6.1), the farm has a high score for water quality and use of alternative water resources, therefore its management could serve as an example for other farms. On the other hand, the efficiency of water and energy use is low, so specific management aspects of well performing farms for these issues might inspire this example farm. Despite the mediocre scores for the use of nutrients, the farm is still better than average for this theme, which indicates that the group has a high potential for improvement. Here, the invited expert attending the meeting could help to analyse the problem and to advise the farmers on management options that could improve the use of nutrients at their farms.

6.3.2. Results of the end-use validation

In the following, we summarize and discuss the responses of the two potential end-user groups for the three preset categories.

6.3.2.1. The indicators as decision aid tools

- The members of the steering committee generally found the indicators useful tools for getting a first evaluation of a farm's management related to a specific sustainability theme. However, in order to be able to take real management decisions or to formulate specific advice, farm-specific additional information was considered necessary. This information can be received e.g. by talking to farmers, by analysing soil, manure or feed samples or by considering specific farm infrastructure. According to the farmers, calculating the indicators should not be considered a goal on itself; instead the indicators are a starting point for taking practical management measures.
- The use of indicator scores was considered necessary in order to be able to position the calculated, absolute indicator values. Without the use of benchmark values, the absolute indicator values were often considered quite meaningless. However, interpretation of the absolute indicator values was considered necessary for locating possible problems and for formulating management advice. Most respondents agreed on the proposed benchmark values (used to score the indicators). Especially the use of indicator values of the 10 % best performing and 10% lowest performing farms as benchmarks was appreciated, since this results in a dynamic and motivating tool for farmers, setting realistic goals.

These responses confirm that the indicators are valuable to the potential end-users in feeding decisions and guiding actions. However, additional information ('the drivers behind the indicator') is often required to decide on appropriate measures and to actually take action.

- Generally, both 'N surplus' and 'N use efficiency' were considered relevant and useful indicators. However, most respondents agreed that additional information is necessary to discover bottlenecks in N use on the farm. Therefore, the project leader of 'Sterk met Melk', composed a detailed N-cycle of each farm, considering all possible N flows. All respondents agreed that at first, it was very difficult to interpret the information gathered in the N-cycle and that it had to be explained to them several times. However, once they got insight in the N-cycle, most respondents found it a very interesting tool to take management decisions on improving a farm's N use.

Theoretically, the N-cycle does not contribute to a better evaluation of the nutrient use, since it is merely an itemization of the already used indicators N surplus and N use efficiency. Moreover, much more detailed data needs to be collected to compose the N-cycle, compared to the presently used indicators, which are based on farm accountancy data. On the other hand, the N-cycle was considered valuable to the potential end-users for translating indicator scores into management measures, although all respondents agreed that it was difficult to understand all interrelations. Therefore, we suggest to evaluate nutrient use by the initial indicators N surplus and N use efficiency, but to additionally provide the possibility of performing an optional, more detailed analysis of the farm's complete N-cycle, depending on the mutual interests and needs of the farmer and farm advisor.

- All respondents found it difficult to fully comprehend the meaning of the energy use efficiency, since this indicator integrates many management related aspects. Therefore, it is not immediately clear which management aspects have the most significant influence on the indicator. As a solution, the project leader proposed to split up the indicator into direct energy use efficiency and indirect energy use efficiency, which was approved by all respondents. Farmers were especially interested in the electricity use – as part of the direct energy use - not only because this involves a considerable financial cost, but also because its efficiency can be improved substantially. The indicator 'use of renewable energy' is considered a relevant indicator, although none of the participating farms currently uses renewable energy sources. Nevertheless, all respondents agreed that this aspect will become more important in the future.

Splitting up the indicator 'energy use efficiency' into 'direct energy use efficiency' and 'indirect energy use efficiency' does not influence the general evaluation of the energy use on dairy farms. However, since this split-up was preferred by all respondents, we suggest to replace the original indicator by the two indicators evaluating the efficiency of direct and indirect energy use separately.

- All proposed indicators for water use and water quality were considered relevant and comprehensible.
- Some members of the steering committee proposed to invert the efficiency indicators (e.g. m³ water use per l milk), since this presentation is more similar to the economic rationale they are familiar with, namely the cost per unit of production.

Although theoretically, interpretation of the environmental intensity indicators (environmental impact per unit of product output) results in the same conclusion as the efficiency indicators – minimum environmental impact versus maximum output - we prefer to hold on to the definition of eco-efficiency, which is considered an important major principle of ecologically sustainable agricultural production (Nevens et al., 2007) and forms the scientific framework for our indicator selection. However, this example shows that the calculation of some indicators is new to farmers and farm advisors and hence it is not obvious for them to interpret the results. This should be kept in mind when the tool is presented to potential users for the first time; detailed training or guidance should be considered.

6.3.2.2. MOTIFS as a decision aid tool and communication tool

- The respondents generally agreed that MOTIFS gives a good overview of all relevant aspects of farm sustainability and that it allows the selection of aspects that need specific attention. Therefore, the members of the steering committee generally considered MOTIFS a useful starting point for advising farmers. However, they found additional information as well as hard figures - such as the absolute indicator values and additional farm-specific information - necessary to enable specific and concrete farm advice.
- One member of the steering committee mentioned that MOTIFS could also be a useful instrument to make decisions on new investments. Using MOTIFS, the attention is drawn to specific aspects of sustainability that should be considered when planning a particular investment. Related to this, the farmers might compare integrated graphs, e.g. before and after specific management measures were taken, or they might follow up on the general evolution of the farm's sustainability in time.
- All respondents considered MOTIFS a useful tool for communicating on sustainability in a very concrete way, since it allows farmers to compare their individual results for specific sustainability themes; this often initiates discussions about concrete and practical aspects of farm management.

These responses confirm that MOTIFS is seen as a valuable decision-aid tool for the potential end-users, a tool that allows to make 'sustainability' concrete. However, once again, additional information is found necessary for giving specific advice or taking decisions on specific management measures. This additional information can be supplied under different forms, for example by calculating a detailed N-cycle or through a more detailed calculation of the different aspects of energy use. However, it will be difficult to capture the enormous variation of possible management aspects underpinning different sustainability performances between farms, into one final parameter or into a mathematical model explaining

everything. Therefore, we suggest to apply MOTIFS in such a way that case- and site-specific advice is provided to farmers (as also suggested by von Wirén-Lehr, 2001), by using it as a communication tool in discussions between farmers and farm advisors, or between farmers in a discussion group. The exchange of expertise and practical knowledge that is available in such a group is expected to result in a more effective advice than would be possible by using models or detailed measures.

- Most respondents considered the design of MOTIFS (an adapted radar graph) appropriate. Some respondents – mainly farmers – would prefer to use bar graphs, since they are more familiar with this type of presentation. In particular, the indication of the average scores of a representative group of comparable farms was considered an important and very useful asset.

The use of a radar graph is new to most respondents and the comments indicate that they might need time to understand and get used to this way of presentation. Nevertheless, since the current design of MOTIFS is the result of a profound scientific research and was approved by a feedback group of experts and stakeholders, we will continue to use the radar graph presentation.

- Generally, the respondents found that ideally, communication about sustainability should be organised in two steps: (i) an individual discussion between farmer and advisor, using MOTIFS to highlight the strengths and weaknesses of the farm and (ii) a group discussion between farmers, where they can compare results, discuss technical aspects of farm management and learn from each other. Especially this second step seemed to be very important for the farmers; in fact, for some farmers the discussion sessions were the most important reason to participate in the 'Sterk met Melk' project. The farmers found these meetings very useful to learn from each other, to find solutions for specific problems, or just to hear each other's opinion on specific issues.

This response shows that farmers highly appreciate the learning aspect that is part of the practical application of MOTIFS in the 'Sterk met Melk' project. This confirms our previous statement concerning the use of MOTIFS in discussion groups to establish case- and site-specific advice. Structurally including such a learning process of feedback, analysis and reflection in the practical application of MOTIFS, is essential for the tool to evolve from a mere measurement system to a core management system (Kaplan and Norton, 1996).

6.3.2.3. Willingness to use MOTIFS in practice

- All members of the steering committee found it important to pay attention to sustainability and to take into account sustainability aspects when advising farmers on management issues. However, opinions varied from 'it is essential, since a sustainable farm is one that can last for a long time' to 'well, it's just something we have to do, it is something society and legislation demands'. For the farmers, 'sustainability' seemed to have a quite negative connotation, since the word was first introduced to them in a period when agriculture was assigned as a strong provoker of environmental problems in Flanders. Accordingly, farmers were urgently demanded to reduce negative impacts of agriculture to the environment ('be more sustainable'). Through the project, the farmers became aware that economic and social aspects are also considered in 'sustainability' and that these aspects can go hand in hand with ecological issues. However, the farmers felt that people outside the project are not yet familiar with this 'new' meaning of the word 'sustainability' and they found it important to make efforts on communicating this to the 'outer world'.
- The respondents generally agreed on the selected themes – use of nutrients, water and energy and water quality – for evaluating ecological sustainability of Flemish dairy farms. Particularly the themes related to water management were considered of topical interest to the farmers, since some of them are already being confronted with water shortage and inferior quality of deep groundwater due to excessive use. Also, both end-user groups agreed that water management at many farms can be improved considerably.
- The respondents agreed that the most obvious added value of MOTIFS compared to specialist management advice, is its ability to present an objective overview of all important aspects of a farm and its management. Hereby, they approved of the calculation methods for the different indicators and/or had confidence in their scientific soundness.

These responses show a support base for the concept of sustainability itself among farmers and farm advisors. They consider it important to communicate about sustainability and to strive for a more sustainable farm management. Consequently, MOTIFS is considered a useful tool with an added value compared to other types of farm advice. The potential end-users seem to have confidence in the tool and the information derived from it, confirming the tool's credibility.

- By calculating the indicators, the farmers found themselves confronted with the fact that they generally do not collect sufficient data and that they are unaware of many relevant aspects that influence their farm. They confirmed

that they had learned from the project that collecting more data allows for a better insight into their farm management. On the other hand, some farmers felt they already spend a lot of time on administrative tasks involving the collection of data. Nevertheless, they showed a willingness to collect additional data on management aspects, provided that the end-purpose is made very clear - i.e. which useful information will they retrieve from it? They also found it important to see the economic gain they can get from evaluating and possibly improving specific management aspects.

This response shows that the farmers realise that data collection is essential to come to (new) insights into their farm and its management. This relates to the theory of Ackoff (1989), who identified a hierarchy stretching from data, through information and knowledge to understanding. In order to take action, people must first come to an understanding of the system (e.g. a farm and its management), by moving successively through the different categories. MOTIFS can help farmers move through these categories and synthesize understanding from data. An important aspect to keep in mind is that the farmers' willingness to collect new data depends on the understanding they will eventually retrieve from it. This benefit should be made as clear to them as possible; and of course, MOTIFS should prove this.

- All respondents of both end-user groups agreed that it would be interesting to use MOTIFS on a regular basis during meetings between farmers and farm advisors to discuss farm management; provided that indicator values, scores and radar graphs are readily available, with little effort required for data collection and calculation on both sides (e.g. as a software application implemented in existing accountancy programs). The farmers did not intend to use MOTIFS if they would have to do everything themselves: collecting data, calculating the indicators and interpreting the results.
- Both end-user groups advised to make maximum use of farm accountancy data to calculate the indicators, since these data are already collected by the farmer. For such indicators (e.g. energy use efficiency), data acquisition and indicator calculation was generally considered neither difficult nor time consuming. Data collection for the indicators for nutrient use and water use on the other hand were generally considered more difficult and often a matter of guessing. These problems could however be avoided in the future, by a priori making clear which data should be collected within a specific year.

These responses show that farmers and farm advisors are willing to use MOTIFS in practice on a regular basis. However, a critical success factor is the tool's user-friendliness: indicator values, scores and radar graphs should be readily available, with little effort required for (extra) data collection and calculation. For

that reason, the Social Sciences Unit of the Flemish Institute for Agricultural and Fisheries Research is currently developing a software application that allows the implementation of MOTIFS in existing accountancy software used by farm advisors. Although the farmers expressed their interest in MOTIFS, they did not intend to use it if they would have to collect data, calculate the indicators and interpret the results themselves. This suggests that the best strategy for practical application of MOTIFS on Flemish farms is to introduce the tool to farmers through farm advisors.

6.4. Conclusions

In this study we developed and applied a validation procedure for MOTIFS, an indicator-based tool for sustainability monitoring of Flemish dairy farms. In our opinion, the presented procedure can also be used to validate other sustainability indicators and indicator-based sustainability monitoring tools.

The methodology has proven to be very helpful, not only for the scientific design of the tool and selected indicators, but also to check the willingness of potential end-users to effectively use the tool in practice. In this way, the indicators and monitoring tool and their way of application can be continuously updated and improved. We consider the accuracy and credibility evaluation of sustainability indicators and indicator-based monitoring tools an essential aspect of their development process. After all, progress towards a more sustainable agricultural production can only be made when the objectives defined by different stakeholders (scientists, farmers, experts, etc.) can be translated into practical measures. A first step is to develop a system that allows this translation, but a second important step is to implement the system effectively in farming practice. The presented validation methodology is helpful for both steps and is a first effort to make sustainability truly operational at the farm level.

Based on the end-use validation, we conclude that MOTIFS is a potentially effective sustainability monitoring *and* management tool, since it has major assets that should be incorporated in any indicator-based system:

- Positioning: MOTIFS allows positioning the strong and weak aspects of a farm and can hence be used to perform a SWOT analysis, identifying a farm's strengths, weaknesses, opportunities and threats.
- Informing: MOTIFS can provide farmers with information that helps them to take action and make decisions, e.g. concerning new investments.
- Learning: MOTIFS can guide farmers through the process of assembling understanding from information and data. This learning aspect should be

strengthened through an optimal application of the tool – e.g. by organising discussion sessions among farmers where they can learn from one another.

- Communicating: MOTIFS allows communication in a concrete and tangible way about hard-to-identify concepts such as 'sustainability'.

Finally, we emphasize that MOTIFS should be applied as a communication, informing and learning system, and not as a controlling system.

Summary, conclusions and recommendations



Summary, conclusions and recommendations

7.1. Recalling the research objectives

This research had two major objectives: to make sustainability concrete and to make sustainability operational on Flemish farms. To achieve these objectives, we identified four phases in the research project:

- designing indicators that make 'sustainability' concrete at the farm level and that enable to monitor progress of Flemish farms towards sustainability;
- aggregating the indicators into an integrated farm sustainability monitoring tool;
- developing and applying a validation procedure for the indicators and the monitoring tool as a whole;
- making suggestions for improving the tool and its effective application in practice.

In this chapter, we summarize and discuss the research issues and main conclusions for each of these four phases. An overview is provided in Figure 7.1.

In addition, we formulate some recommendations (in italics) to effectively make sustainability work on Flemish farms in the future. An overview is provided in Figure 7.2.

Objective 1: concretisation of sustainability		Objective 2: operationalisation of sustainability	
Phase 1 Designing (ecological) indicators	Phase 2 Aggregating the indicators in a farm sustainability monitoring tool	Phase 3 Validating the indicators and the monitoring tool	Phase 4 Making suggestions to improve the tool and its effective application in practice
<p><u>Methodology:</u></p> <p>Conceptual framework of 'vision → themes → indicators'</p> <p>Transdisciplinary approach</p> <p><u>Results:</u></p> <p>Biodiversity indicators at regional level</p> <p>Indicators for water use and water quality at farm level</p> <p>Indicators for energy use at farm level</p> <p>Eco-efficiency, concrete at Flemish dairy farms</p>	<p><u>Methodology:</u></p> <p>Conceptual framework of defining benchmarks and weights and visually aggregating indicator scores</p> <p>Some amount of pragmatism</p> <p><u>Results:</u></p> <p>MOTIFS: multi-level visual monitoring tool for integrated (ecological, economic and social) farm sustainability</p> <p>Special attention paid to user-friendly and communicative design</p>	<p><u>Methodology:</u></p> <p>Conceptual framework of accuracy evaluation and credibility evaluation</p> <p>Transdisciplinary approach</p> <p>Qualitative research</p> <p><u>Results:</u></p> <p>The developed indicators were found valuable to the potential end-users to feed decisions and guide actions.</p> <p>MOTIFS was considered a valuable decision-aid tool that allows to make 'sustainability' concrete.</p>	<p>MOTIFS is considered a potentially effective sustainability monitoring <i>and</i> management tool that has major assets that should be incorporated in any indicator- based system: positioning, informing, learning and communicating.</p> <p>Structurally including a learning process of feedback, analysis and reflection in the practical application of MOTIFS, is essential for the system to evolve from a mere measurement system to a core management system.</p>

Figure 7.1. Major results and conclusions for the four research phases

Objective 1: concretisation of sustainability		Objective 2: operationalisation of sustainability	
Phase 1 Designing (ecological) indicators	Phase 2 Aggregating the indicators in a farm sustainability monitoring tool	Phase 3 Validating the indicators and the monitoring tool	Phase 4 Making suggestions to improve the tool and its effective application in practice
<p>The three steps of the described methodology (vision → themes → indicators) should be considered during the development of any indicator-based monitoring tool to avoid using indicators that are not relevant for the problem at issue, or that are selected based on the availability of data rather than on scientific soundness and relevance.</p>	<p>MOTIFS is considered a suitable guide in optimising current farming systems, but we should be aware of the potential danger to lock even optimised systems into suboptimal future development paths.</p> <p>Stakeholder participation should be considered an essential aspect in the development of any indicator-based sustainability monitoring system.</p> <p>Considering a system's effective practical application, its development and validation should be based on interactive, transdisciplinary processes.</p>	<p>Any (newly developed) sustainability indicator or indicator-based monitoring tool should be validated. We consider this an essential aspect of their development process.</p> <p>Each suggestion made by the end-users should be considered and tested for its (scientific) soundness and relevance within the defined vision and the underlying major principles.</p>	<p>An effective practical application of MOTIFS on Flemish farms will be most likely to succeed when the system is introduced to farmers by farm advisors.</p> <p>A critical success factor is the system's user-friendliness. For that reason, a software application that allows to implement MOTIFS in existing accountancy software used by farm advisors is currently developed.</p> <p>MOTIFS should be applied as a communication, informing and learning system, not as a controlling system</p>

Figure 7.2. Major recommendations for the four research phases

7.2. Phase 1: designing indicators

In the first phase of the research project we designed indicators that make 'sustainability' concrete at the farm level and that monitor progress of Flemish farms towards sustainability. We therefore developed a methodology to design sustainability indicators and we applied this methodology to a number of specific ecological sustainability themes: biodiversity, water use, water quality and energy use.

7.2.1. A methodology for indicator design (Chapter 5)

The developed methodology fits within a theoretical framework of 'transition', considering sustainable development as a long-term, complex and drastic process of change. Within this framework, sustainable development processes are based on a well-conceived vision, with concrete and inspiring images of an envisioned future.

The proposed methodology consists of three steps:

- developing a supported vision;
- translating the major principles of the vision into concrete themes, to make 'sustainability' more tangible at the level of practice and to enable effective actions;
- designing relevant indicators, to further concretize the selected sustainability themes.

A process of vision development was performed in Flanders, based on a transdisciplinary dialogue between the many stakeholders of Flemish agriculture. According to the major principles of the supported vision, an ecological sustainable agricultural system:

- functions within a stable agro-ecosystem, which can be ensured by (i) optimizing the preconditions for production – i.e. optimizing the quality of natural resources (air, soil, water); (ii) maximally closing physical and biological cycles; and (iii) preserving a broad ecological base – i.e. maximally maintaining and using biodiversity;
- works at the highest levels of eco-efficiency. According to the principle 'produce more from less', this means that it adds maximum value with minimum use of resources and/or with minimum environmental impact;

- maximizes its positive impacts on the environment, e.g. by green services (biodiversity, nature) and blue services (water management).

These major principles were translated into 3 relevant themes for ecological sustainable agricultural production: use of inputs (nutrients, energy, water and pesticides), quality of natural resources (water, air and soil) and biodiversity.

For each theme, existing indicators were selected from (scientific) literature, whenever they complied with the basic principles of the supported vision and the derived themes. Subsequent quality criteria, relating to the indicators' causality, sensitivity, solidness, comprehensibility and the use of benchmarks were imposed. When little or no scientific information was available, experts and stakeholders were consulted or new fundamental research was performed. Finally, before accepting an indicator, it was presented to a feedback group of experts and stakeholders, to validate its design and output. In the work presented here, this methodology was specifically applied to develop indicators for a number of ecological sustainability themes of Flemish farms: biodiversity, water use, water quality and energy use.

We recommend to consider the three steps of the described methodology (from vision over themes to indicators) when developing an indicator-based monitoring tool. This avoids using indicators that are not relevant for the problem at hand, or that are selected based on the availability of data rather than on scientific soundness and relevance.

7.2.2. Indicators for biodiversity (Chapter 2)

Biodiversity indicators have to fulfill different requirements depending on the geographic level considered (e.g. field – farm – region – country) and on the goals that should be achieved. The establishment of a hierarchic system of indicators, including their linking-up considering the different levels and goals, is recommended.

At farm level, an evaluation tool of management aspects that are related to biodiversity would allow us to evaluate a specific farm on its sustainable use of biodiversity and would provide farmers an insight into different measures for maintaining biodiversity. However, a major concern in developing such an evaluation tool of management-related aspects, is to unfold the link between the management measures taken at the farm and their actual contribution to biodiversity at the regional level. Biodiversity is not limited to farm boundaries. Hence, we considered it primarily important to be able to evaluate the state and evolution of biodiversity at the regional level, before effective management measures at farm level can be identified and evaluated. Therefore, the specific

objective of this chapter was to develop indicators for agrobiodiversity at the (regional) level of Flemish agricultural landscapes.

A farm evaluation tool for biodiversity should take into account the link between management measures taken at farm level and their effect on biodiversity at the regional level.

In chapter 2, we describe two case studies. In the first study, indicators for diversity between and within agricultural crops in Flanders were developed. Shannon and evenness indices were selected as indicators for diversity between crops. Genetic diversity within three crops was assessed by the Shannon and evenness indices and by the genetic relatedness between varieties. Application of the indicators showed that despite an increase in the number of crops, the overall crop diversity in Flanders did not increase between 1950 and 2002. This was caused by the increasing dominance of a limited number of arable crops, maize in particular. And specifically within this latter crop, the indicators showed a decrease in genetic diversity between varieties (1980 versus 2002).

Considering its importance in sustainable agriculture and the fact that there are (crop dependent) indications of a decrease in genetic diversity of crops in Flanders during the last few decades, we state that measures should be taken to maintain it at least at its present level. The Governmental testing system of plant varieties might be an excellent platform to watch this problem.

Genetic diversity of crops should be monitored more closely in the future and it should be taken into account when developing new and sustainable agricultural production systems.

In the second study, we proposed an objective, statistically-based method to select indicator species for biodiversity within Flemish agricultural ecosystems and their natural environment. As a case study, we applied this method to select indicator species of farmland bird diversity.

For each Flemish ecoregion⁷, 1x1km observation squares formed the basis of the analysis. From a list of 45 farmland birds, a species was selected as a significant indicator when the average species richness of the squares containing the considered species was significantly higher than the average species richness of the squares where the species was absent. Additional selection criteria were imposed: (i) we only retained species that were present in more than 20% and less than 80% of the considered 1x1km squares and (ii) we only retained the

⁷ An eco-region groups spatial areas that are considered homogeneous in the field of geological, geomorphologic, groundwater and surface water characteristics and related soil types.

indicator species for which the average agricultural area of the squares with the species was higher than the average agricultural area of the squares without the species. As a final selection, per ecoregion, we retained the top-three indicator species, ranked according to the highest farmland bird species richness.

Population trends of these selected farmland bird indicator species could be used to indicate changes in the diversity of farmland birds in Flanders. Moreover, ecological knowledge relating to biotope quality, quantity and configuration of each indicator species can be used for region-specific management planning and/or evaluation.

Considering that it is unlikely that indicator species from a single taxonomic group (e.g. birds) will provide sufficient information on the richness of an entire biota, the selected list of indicator bird species should be extended with indicator species of other taxonomic groups to be able to cover all aspects of biodiversity. However, this would require a species monitoring - and related funding - much more elaborate than is currently available in Flanders.

7.2.3. Indicators for water use (Chapter 6)

We developed two indicators to evaluate the water use on Flemish farms: water use efficiency and use of alternative water resources. For dairy farms, water use efficiency is calculated as the ratio of produced milk (litre) to the total amount of water used on the farm (m³). The second indicator, use of alternative water resources, assesses the farmer's management efforts to use rainwater, surface water or shallow groundwater as alternatives to deep groundwater and drinking water (usually retrieved from purified deep groundwater). The indicator is calculated as a weighted average of the shares of rainwater (%RW), surface water (%SW) and shallow groundwater (%SGW) in the farm's total water use: use of alternative water resources = 0.44 %RW + 0.34 %SW + 0.22 %SGW.

This research has shown that, despite the increasing interest for sustainable water use among Flemish farmers, hardly any data on the (alternative) water use of Flemish farms are available. To effectively handle problems of water use in the future and to allow the implementation of new management techniques related to sustainable water use, it is essential to start measuring the actual amounts of water use from different sources.

7.2.4. Indicators for water quality (Chapter 6)

To evaluate water quality, we developed an indicator related to wastewater management. The resulting score is based on the comparison of the actually

applied wastewater management techniques on the farm with the available (combinable) alternatives as defined by the Best Available Techniques. For dairy farms, the indicator score is calculated as the average of the scores for each of three considered types of wastewater: (i) from cleaning milking machinery and milk tank, (ii) contaminated with manure and (iii) silage leachate and run-off from bunker silos.

Since only little information was found on indicators for sustainable water management at non-irrigated dairy farms, we consulted experts to select and design relevant indicators for water use and water quality. Several Flemish agricultural research centres have considerable experience on water management at Flemish farms and extensive expertise concerning water use and management is available at the Flemish Environment Agency. Therefore, experts of these institutes were consulted during the design of the indicators for water use and water quality. Meetings with experts were organised on a regular basis to choose and develop the relevant indicators, to select benchmarks and to discuss practical problems concerning data use.

7.2.5. Indicators for energy use (Chapter 3)

We elaborated two indicators for energy use at Flemish farms: energy use efficiency and use of renewable energy.

Energy use efficiency expresses the amount of product produced per unit of consumed energy. We determined the energy use efficiency of a representative set (Flemish Farm Accountancy Data Network, FADN) of specialised dairy, arable and pig farms in Flanders and studied the changes over time. We observed that the use of mineral fertilisers and animal feed accounted for a high share (up to 70%) of the total energy use on the farms. Diesel use took the major part of direct energy use. For dairy and arable farms, total energy use per ha has decreased substantially from 1989-1990 to 2000-2001; on pig farms, energy use per finishing pig equivalent (FPE) in 1997-1998 was comparable to that in 1989-1990. The most energy efficient dairy and pig farms were intensive farms, combining a high production with a low energy use and producing a gross value added per unit of production comparable to, or even higher than the average.

Based on the energy use efficiencies of the top 5% farms, target values were set of 35 l milk 100 MJ⁻¹ and 7.5 kg live weight 100 MJ⁻¹ for energy use on Flemish dairy and farrow-to-finish pig farms, respectively. On arable farms, the energy use efficiency was highly dependent on the grown crops, hence the indicator should be calculated on field level, for each separate crop.

Considering the high share of indirect energy use on Flemish farms – particularly incorporated in mineral fertilisers and animal feed - it is important that this aspect is monitored at Flemish farms and discussed with farmers.

The indicator 'use of renewable energy' puts the share of renewable energy sources that are used on the farm within the overall direct energy use. Although very few Flemish farms currently use renewable energy sources, this aspect is expected to become more important in the future (chapter 6).

7.2.6. Eco-efficiency (Chapter 4)

As described by the major principles of the supported vision on a sustainable Flemish agriculture, working at the highest level eco-efficiency is an important asset of ecologically sustainable agricultural systems. 'Eco-efficiency' is a management approach that was acknowledged at the 1992 Rio Earth Summit as a way for companies and businesses to contribute to sustainable development. It has been given many definitions, all of them, however, adding up to the one principle 'produce more from less' or adding maximum value with minimum use of resources and/or with minimum environmental impact.

To some extent, we made this management approach concrete at Flemish dairy farms through the developed indicators of ecological sustainability (e.g. energy use efficiency).

We determined specific eco-efficiencies of a representative set of Flemish dairy farms (FADN data). Hereby, we measured eco-efficiency as a combination of nitrogen (N) use efficiency and energy use efficiency, where N use efficiency (l milk kg⁻¹ N surplus) is the ratio of the amount of produced milk to the farm-gate N surplus (= N input – N output). Energy use efficiency (l milk 100MJ⁻¹) is the ratio of the amount of produced milk to the total (direct + indirect) consumed energy.

This study showed that between 1989–1990 and 2000–2001, the average N use efficiency of the FADN-farms increased from 27 to 40 l milk kg⁻¹ N surplus and average energy use efficiency increased from 22 to 27 l milk 100MJ⁻¹, indicating an overall increase of eco-efficiency of these farms. The dairy farms with the highest eco-efficiencies were characterised by a higher milk production (per cow and per ha), a lower N surplus, a lower energy consumption and a higher gross value-added.

These results show that on the studied farms, higher eco-efficiency went hand in hand with better economic results. We recommend that such findings are explicitly communicated to farmers, since they highly appreciate seeing the

economic gain they can get from evaluating and possibly improving specific (ecologically oriented) management aspects (Chapter 6).

7.2.7. Conclusion

In the first phase, we conceptualised a methodology to design sustainability indicators, strongly characterized by a transdisciplinary approach within a conceptual framework of 'vision → themes → indicators'.

We applied this methodology to develop indicators for some specific ecological sustainability themes: biodiversity, water use, water quality and energy use. These indicators make 'sustainability' concrete at the farm level and allow us to monitor progress of Flemish farms towards sustainability.

7.3. Phase 2: aggregating the indicators (Chapter 5)

In the second phase, we aggregated the developed indicators into an integrated farm sustainability monitoring tool. We therefore developed a methodology to aggregate sustainability indicators and applied the resulting monitoring tool in practice on a Flemish specialised dairy farm as a first case study.

7.3.1. A methodology to aggregate the indicators

The methodology consists of three steps:

- defining benchmarks to rescale indicator values into scores (0 to 100);
- defining indicator weights;
- aggregating the indicator scores.

In a first step, we defined minimum (B_{\min}) and maximum (B_{\max}) benchmarks for the developed indicators, enabling us to rescale indicator values into scores between 0 (indicating a worst-case situation) and 100 (indicating assumed maximum sustainability). For the developed indicators described in the previous section, we applied the following approaches to define benchmark values:

- The indicator values of a reference group of comparable farms (for the indicators of energy and water use): the 10% best performing farms delimit the 100 score (B_{\max}), the 10% lowest performing farms the 0 score (B_{\min}). Intermediate indicator values are transferred into linearly intermediate scores.
- Best Available Techniques (BAT, for the indicators of water quality): the indicator score is defined by the share of waste water management techniques that are actually applied on the farm, compared to the maximum package of combinable alternatives of BAT (B_{\max}).
- Scientific knowledge and/or legislative standards: e.g. a farm 'nitrogen (N)-surplus' of 150 kg ha⁻¹ (B_{\max}) or less is compliant with the European Nitrates Directive on soil water protection (Nevens et al., 2006).

In a second step, we weighed the indicators. Hereby, we assumed that all sustainability themes are equally important. This principle takes into account the equality of the economic, ecological and social sustainability dimensions. In line with this principle, also within a specific theme, we considered all indicators equally important and consequently assigned them an equal weight, except when – based on expert opinions or on literature reviews – there was considerable

proof that certain indicators are in fact more important than others when used to evaluate the sustainability of the specific theme.

Finally, we aggregated the scores of the ecological indicators – together with indicators of economic and social aspects – into one tool, MOTIFS (Monitoring Tool for Integrated Farm Sustainability, Figure 7.3). We chose to aggregate the indicators in a graphical tool, allowing a comprehensive overview and mutual comparison of the indicators for different sustainability themes. Graphic methods have been found well suited for an effective communication about sustainability towards farmers.

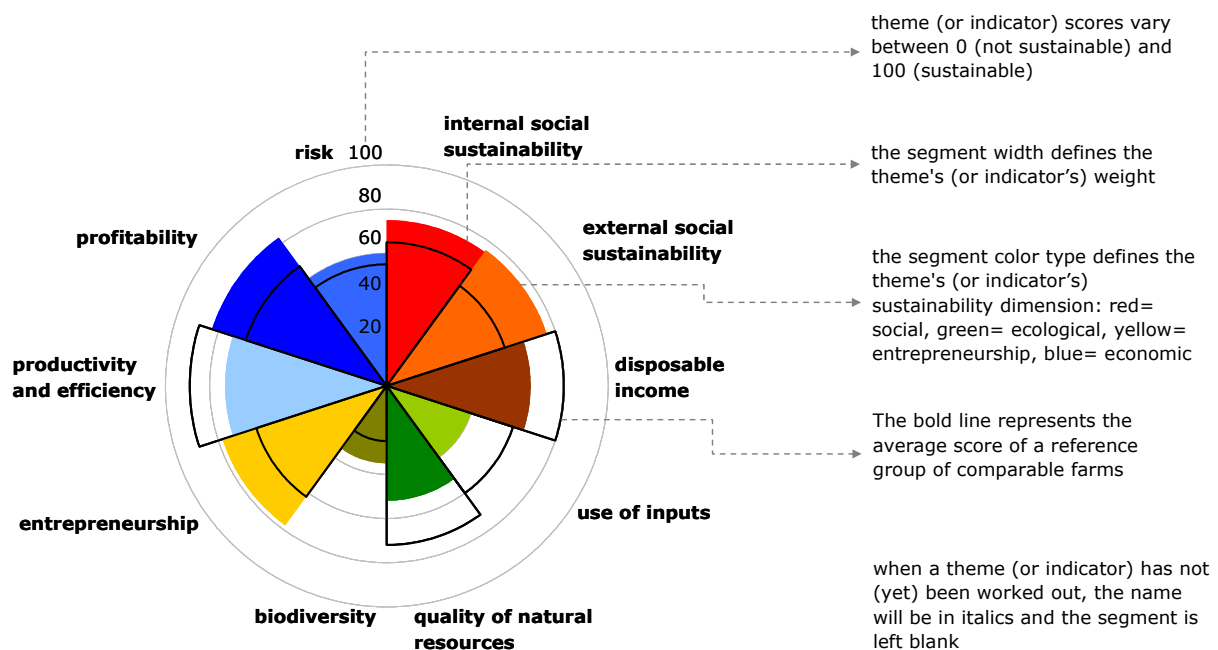


Figure 7.3. MOTIFS, the general picture

We further focused on a user-friendly and communicative design by adding the average indicator scores of a group of comparable farms. MOTIFS is a visual multi-level monitoring tool. Level 1 gives an overview of the farm's overall sustainability (Figure 7.3). Level 2 gives an overview of the sustainability themes within a specific sustainability dimension. In level 3, the indicator scores for a specific theme are visualised. So, starting from an overall view of his farm's sustainability, a farmer can zoom in on the underlying themes and indicators into as much detail as desired.

As a first case study, we applied MOTIFS on a single Flemish dairy farm. Thereby some of the themes and indicators were not measured yet. Nevertheless, by explicitly including these unmeasured themes and indicators, it is emphasized that the list of measured indicators is not limitative, and that the result thus far is not yet a complete monitoring of the farm's overall sustainability. Moreover,

when the farmer is aware of existing data gaps for indicator calculations, he might be stimulated to collect these necessary farm data.

We consider MOTIFS a suitable guide to optimise current systems, but we should be aware of the potential danger to lock even optimised systems into suboptimal future development paths: optimisation of current systems ('system optimisation') is a first step to translate 'sustainability' in concrete actions. However, for genuine sustainable systems, totally new production systems should be considered and/or designed ('system innovation').

7.3.2. Conclusion

We developed a user-friendly and strongly communicative tool to measure progress towards integrated (economic *and* ecological *and* social) sustainable dairy farming systems. The tool fits within a well-founded methodological framework and is based on a set of relevant indicators. Stakeholder participation and expert consulting took an important place in the development process.

Our approach was characterized by some amount of pragmatism (in the choice of benchmarks, weights etc.). We consider this pragmatic approach justified, especially baring in mind our second research objective: developing a tool that actually triggers and guides action and is practically applicable *and* applied on Flemish farms.

Application of MOTIFS on 20 Flemish dairy farms (Chapter 6)

A selection of sustainability themes extracted from MOTIFS is studied on 20 dairy farms, located in the North-Western part of Flanders, to monitor sustainability and stimulate communication and exchange of knowledge between farmers. These 20 farms participate in a Leader+ project called 'Sterk met Melk (Strong with milk, 2006-2008)'. Leader+ (Liaisons Entre Actions de Développement de l'Economie Rurale) is an initiative financed by EU structural funds and is designed to help rural actors consider the long-term potential of their local region.

Practically, a project leader visits each farm every three months and collects data, calculates indicators and discusses the results with each farmer individually. In addition, she organises communication sessions for the whole group of participating farmers, in which they can discuss their 'MOTIFS-results' for a specific sustainability theme, together with the project leader and an invited expert. A bi-annual meeting of the project's steering committee – made up of representatives of farmer organisations, agricultural research institutes and local policymakers – advises on the methodological and structural aspects of the project.

During the first period (2006-2007), the project has focused on ecological sustainability aspects: nutrient use, energy use, water use and water quality. Besides these ecological themes, economic and social aspects will also be considered in 2008.

We consider the end-use validation of MOTIFS of critical importance to its optimization and continuous improvement. For that reason we encourage its application on as many practical Flemish farms as possible, even though at this stage not all indicators have been worked out in detail.



7.4. Phase 3+4: Validation and suggestions (Chapter 6)

In the final phases of the research, we developed a detailed validation procedure for indicator-based sustainability monitoring tools and applied this procedure to validate MOTIFS and the developed ecological sustainability indicators. Based on the experiences from the indicator development and validation processes, we made some suggestions concerning the design of MOTIFS and its effective application in practice.

7.4.1. A validation procedure for indicator-based sustainability monitoring tools

In general, validation checks the extent to which a developed instrument or solution meets the anticipated criteria. Thereby, validation verifies that the instrument has a satisfactory degree of accuracy, consistent with its intended application. Another asset is 'credibility', expressing the potential users' confidence in a system, and hence their willingness to effectively use it.

The validation procedure consists of two steps:

- an accuracy evaluation, comprising a design validation and an output validation;
- a credibility evaluation, comprising an end-use validation.

7.4.1.1. Accuracy evaluation

Accuracy evaluation relates to the degree to which a system or an indicator reaches its intended goals. An accuracy evaluation comprises a 'design validation' and an 'output validation'. Design validation checks the scientific quality of the construction or design of the indicator or the system, and output validation is an evaluation of the information that is supplied by the indicator or system's output.

The intended goals of the developed ecological indicators in this study were (i) to make sustainability concrete at Flemish farms, (ii) to measure sustainability of Flemish farms and (iii) to motivate and guide farmers to take effective actions towards more sustainable ways of agricultural production. MOTIFS was designed as a decision aid tool and as a communication tool.

We used a transdisciplinary approach of expert and stakeholder participation to simultaneously carry out the design and output validation of MOTIFS and the ecological indicators. For each indicator, feedback groups of experts and stakeholders discussed the (perceived) relevance and underlying methodological

choices such as indicator design, data use, choice of benchmarks and weight. This method was also used to validate the design of MOTIFS: a feedback group discussed the methodological choices concerning indicator aggregation (visual versus numerical) and aspects of design (adapted radar graph versus bar graph). We also consulted experts during the selection and design of relevant indicators for water use and water quality. In addition, we validated the scientific quality of MOTIFS and its sustainability indicators by compiling existing scientific knowledge from scientific publications and by publishing our methodologies and results in peer-reviewed scientific journals.

The applied methodology of literature research and/or expert consulting combined with a transdisciplinary approach of stakeholder participation was found very useful in the design and validation of the ecological sustainability indicators. Moreover, discussions among stakeholders - based on scientific information - may themselves contribute to the development of sustainable farming systems. They are essential for translating shared understandings and interpretations into collective action on sustainable development.

We consider stakeholder participation an essential aspect of the development of any indicator-based sustainability monitoring tool. Considering a tool's effective practical application, its development and validation should be based on interactive, transdisciplinary processes. This approach not only allows to bridge the gap between science and practice; it also creates a support base for the tool among the stakeholders who are involved in its development.

7.4.1.2. Credibility evaluation

An indicator or system's credibility evaluation relates to the degree of confidence potential end-users have in it, and hence their willingness to effectively use it in practice. This involves an end-use validation.

We designed a test to evaluate (i) the end-use value of the selected indicators as decision aid tools, (ii) the end-use value of MOTIFS as a decision aid tool and communication tool and (iii) the willingness of potential end-users to use MOTIFS in practice. The test was based on semi-structured interviews.

The responses of the potential end-users (dairy farmers and 'sustainability consultants') confirmed that the indicators are valuable to the potential end-users, to feed decisions and guide actions. Also, MOTIFS was considered a valuable decision-aid tool that allows making 'sustainability' concrete. However, additional information is considered necessary for deciding on appropriate management measures and for actually taking action.

Based on the end-use validation, some specific changes were made to individual indicators. For example, all respondents preferred to split up the indicator 'energy use efficiency' into 'direct energy use efficiency' and 'indirect energy use efficiency'. Since this does not influence the general evaluation of the energy use on dairy farms, we replaced the original indicator by these two separate indicators.

We consider the opinion of potential end-users of the tool of major importance for its effective practical application. Each suggestion made by the end-users should be considered and tested for its scientific soundness and relevance within the defined vision and major principles. Whenever such a suggestion enhances the user-friendliness of the tool and complies with the underlying theory, it should be considered for implementation in the tool. In this way, a sustainability monitoring tool can be continuously updated and improved.

The end-use validation also showed that the calculation of some indicators as well as the use of a radar graphs is new to farmers and farm advisors, and they consequently might need time to understand and get used to this presentation method.

This lack of experience with the calculation and presentation method of the developed indicators should be kept in mind when the tool is presented to potential users for the first time and it shows that detailed training or guidance should be provided.

The farmers strongly appreciated the learning aspect that is included in the practical application of MOTIFS in the 'Sterk met Melk' project, where a group discussion between farmers is organised on a regular basis, in which farmers can compare results, discuss technical aspects of farm management and learn from each other.

Structurally including such a learning process of feedback, analysis and reflection in the practical application of MOTIFS, is essential for the tool to evolve from a mere measurement system to a core management system.

There is a support base for the concept of sustainability among farmers and farm advisors and they consider it important to strive for a more sustainable farm management. Hereby, MOTIFS is considered a useful tool with an added value compared to other types of farm advice. The potential end-users seem to have confidence in the tool and the information derived from it, confirming the tool's credibility.

Farmers and farm advisors claimed to be willing to use MOTIFS in practice on a regular basis. However, a critical success factor is the tool's user-friendliness: indicator values, scores and radar graphs should be readily available, with little effort required for data collection and calculation. For that reason, the Social Sciences Unit of the Flemish Institute for Agricultural and Fisheries Research is currently developing a software application that allows the implementation of MOTIFS in existing accountancy software used by farm advisors.

The end-use validation showed that, although the farmers expressed their interest in MOTIFS, they did not intend to use it if they would have to collect data, calculate the indicators and interpret the results themselves. They found that ideally, MOTIFS should be used during individual discussions between farmer and advisor, using MOTIFS to highlight the strengths and weaknesses of the farm and to compare the farm's results to other farms and during group discussions between farmers, where they can compare results, discuss technical aspects of farm management and learn from each other. Especially this second step was very important for the farmers.

This suggests that an effective practical application of MOTIFS on Flemish farms will be most likely to succeed when the tool is introduced to farmers through farm advisors. They are most qualified to discuss the different sustainability aspects in confidence with the farmers, to provide additional information and advice that is essential to decide on appropriate measures and to organise group discussions among farmers.

7.4.2. Conclusion

We developed and applied a validation procedure for MOTIFS. In our opinion, the presented procedure can also be used to validate other sustainability indicators and indicator-based sustainability monitoring tools. The methodology has proven to be very helpful, not only for the scientific design of the tool and the selected indicators, but also to check the willingness of potential end-users to effectively use the tool in practice. In this way, the indicators and monitoring tool and their way of application can be continuously updated and improved.

Progress towards a more sustainable agricultural production can only be made when theoretic objectives can be translated into practical measures. A first step is to develop a system that allows this translation, but a second important step is to implement the system effectively in practice. The presented validation methodology is helpful for both steps and is a first effort to make sustainability truly operational at the farm level.

We recommend that any (newly developed) sustainability indicator or indicator-based monitoring tool is validated. We consider this an essential aspect of their development process.

Based on the end-use validation, we conclude that MOTIFS is a potentially effective sustainability monitoring *and* management tool that has major assets that should be incorporated in any indicator-based system:

- Positioning: MOTIFS allows positioning the strong and weak aspects of a farm and can therefore be used to perform a SWOT analysis, identifying a farm's strengths, weaknesses, opportunities and threats.
- Informing: MOTIFS can help farmers to take action and make decisions, e.g. concerning new investments.
- Learning: MOTIFS can guide farmers through the process of assembling understanding from data. This learning aspect should be strengthened through an optimal practical application of the tool.
- Communicating: MOTIFS allows communication in a concrete and tangible way about hard-to-identify concepts such as 'sustainability'.

Considering these assets, we emphasize that MOTIFS should be applied as a communication, informing and learning system, and not as a controlling system.

7.5. To end

With this research, we believe to have developed an effective instrument that can potentially contribute to a (more) sustainable Flemish agriculture. Potentially, since in the end, its contribution depends on its effective practical application on Flemish farms.

Therefore, we sincerely hope that this research may continue to live in science and practice, that it can find its way to Flemish farmers, that MOTIFS may further be improved and completed and that its effective practical application in the 'Sterk met Melk' project may serve as an example for others who attempt to make sustainability truly operational at the farm level.

Finally, a sustainable agricultural sector can only exist within a sustainable society. Hence, operationalising sustainability is not only the task of Flemish farmers, it equally depends on the responsibility of policy makers and society as a whole.

Hoofdstuk 8

Samenvatting, besluiten en aanbevelingen



Samenvatting, besluiten en aanbevelingen

8.1. Doelstellingen van het onderzoek

Het onderzoek in dit proefschrift had twee doelstelling: concretiseren en operationaliseren van 'duurzaamheid' op Vlaamse landbouwbedrijven. Om deze doelstellingen te bereiken, doorliepen we vier onderzoeksfasen:

- indicatoren ontwerpen die 'duurzaamheid' concreet maken op Vlaamse landbouwbedrijven en die de duurzaamheidsprestaties van deze bedrijven kunnen meten en opvolgen;
- de voorgestelde indicatoren aggregeren in een integrale duurzaamheidsmonitor;
- een methode ontwikkelen (en toepassen) om de voorgestelde indicatoren en de integrale duurzaamheidsmonitor te valideren;
- voorstellen formuleren om de duurzaamheidsmonitor en de effectieve toepassing ervan in de praktijk te verbeteren.

In deze uitgebreide samenvatting verzamelen we de belangrijkste resultaten en conclusies van deze vier onderzoeksfasen (Figuur 8.1).

Daarnaast formuleren we een aantal aanbevelingen om duurzaamheid op een effectieve manier te operationaliseren op Vlaamse landbouwbedrijven (Figuur 8.2). Deze aanbevelingen staan in cursief.

In dit proefschrift lag de nadruk op ecologische aspecten van duurzame landbouw. In een ander onderzoek werden eveneens indicatoren ontwikkeld voor economische en sociale duurzaamheidsaspecten. De resultaten hiervan worden samengevat in het boek 'Erven van de toekomst' (Steunpunt Duurzame Landbouw, 2006).

Doelstelling 1: duurzaamheid concretiseren

Doelstelling 2: duurzaamheid operationaliseren

Fase 1 (Ecologische) indicatoren ontwerpen	Fase 2 Indicatoren aggregeren in een integrale duurzaamheids- monitor	Fase 3 Indicatoren en duurzaamheids- monitor valideren	Fase 4 Voorstellen formuleren om de duurzaamheids- monitor en z'n effectieve toepassing te verbeteren
<p><u>Methode:</u></p> <p>Conceptueel kader van 'visie → thema's → indicatoren'</p> <p>Transdisciplinaire aanpak</p> <p><u>Resultaat:</u></p> <p>Biodiversiteitsindicatoren op regionaal niveau</p> <p>Indicatoren voor watergebruik en -kwaliteit op bedrijfsniveau</p> <p>Indicatoren voor energie- gebruik op bedrijfsniveau</p> <p>Eco-efficiëntie, concreet op bedrijfsniveau</p>	<p><u>Methode:</u></p> <p>Conceptueel kader van 'richtwaarden definiëren', 'gewichten definiëren' en 'indicator scores aggregeren'</p> <p>Zeker pragmatisme</p> <p><u>Resultaat:</u></p> <p>MOTIFS: een gebruiksvriendelijk en communicatief sterk systeem om geïntegreerde (ecologische én economische én sociale) duurzaamheid van melkveebedrijven te meten en op te volgen.</p>	<p><u>Methode:</u></p> <p>Nauwkeurigheidsevaluatie en geloofwaardigheidsevaluatie</p> <p>Transdisciplinaire aanpak</p> <p>Kwalitatief onderzoek</p> <p><u>Resultaat:</u></p> <p>De indicatoren zijn waardevolle instrumenten voor potentiële eindgebruikers om beslissingen te treffen en effectieve acties te ondernemen.</p> <p>MOTIFS is een bruikbaar instrument om het begrip 'duurzaamheid' concreet te maken voor Vlaamse melkveebedrijven.</p>	<p>MOTIFS kan een effectief beoordelings- én managementinstrument zijn voor duurzaamheid op Vlaamse landbouwbedrijven.</p> <p>MOTIFS heeft belangrijke eigenschappen die zouden moeten aanwezig zijn in elk indicatorsysteem: leren, positioneren, informeren, communiceren.</p> <p>MOTIFS kan evolueren van een meetsysteem naar een echt managementsysteem, wanneer we het leerproces van terugkoppelen, analyse en reflectie structureel kunnen inbouwen in de praktische toepassing ervan.</p>

Figuur 8.1. Belangrijkste resultaten en conclusies

Doelstelling 1: duurzaamheid concretiseren

Doelstelling 2: duurzaamheid operationaliseren

Fase 1 (Ecologische) indicatoren ontwerpen	Fase 2 Indicatoren aggregeren in een integrale duurzaamheids- monitor	Fase 3 Indicatoren en duurzaamheids- monitor valideren	Fase 4 Voorstellen formuleren om de duurzaamheids- monitor en z'n effectieve toepassing te verbeteren
<p>De drie stappen van de beschreven methodologie (van visie over thema's naar indicatoren) worden best toegepast bij de ontwikkeling van indicatoren. Zo vermijdt men dat indicatoren worden gebruikt die niet relevant zijn voor het te onderzoeken probleem of die geselecteerd zijn omwille van de beschikbaarheid van gegevens in plaats van hun wetenschappelijke waarde en relevantie.</p>	<p>We beschouwen MOTIFS als een geschikt instrument om bestaande systemen te optimaliseren, maar we moeten ons er van bewust zijn dat zelfs geoptimaliseerde systemen nog steeds niet duurzaam kunnen zijn.</p> <p>We beschouwen het raadplegen van experts en betrokkenen als een essentieel onderdeel in de ontwikkeling van elke indicator of beoordelingssysteem, voornamelijk met betrekking tot de effectieve toepassing ervan in de praktijk.</p>	<p>We raden aan dat men elk (nieuw ontwikkeld) beoordelingssysteem en elke duurzaamheidsindicator valideert. We beschouwen deze validatie als een essentieel onderdeel van hun ontwikkelingsproces.</p> <p>Elke suggestie van eindgebruikers zou moeten worden getest op haar wetenschappelijke waarde en relevantie. Wanneer een suggestie de gebruiksvriendelijkheid van het systeem verbetert binnen de onderliggende theorie, dan moet een aanpassing van het systeem overwogen worden.</p>	<p>Een effectieve toepassing van MOTIFS op Vlaamse landbouwbedrijven kan het best gebeuren door het systeem aan landbouwers te introduceren via bedrijfsbegeleiders.</p> <p>Een kritieke succesfactor is de gebruiksvriendelijkheid van MOTIFS: indicatorwaarden, scores en radardiagrammen moeten gemakkelijk beschikbaar gemaakt worden, met minimale extra inspanningen.</p> <p>MOTIFS wordt best toegepast als een lerend, informerend en communicerend instrument en niet als controle-instrument.</p>

Figuur 8.2. Belangrijkste aanbevelingen

8.2. Fase 1: indicatoren ontwerpen

In de eerste fase van het onderzoek ontwierpen we indicatoren die het begrip 'duurzaamheid' concreet kunnen maken op Vlaamse landbouwbedrijven en die toelaten om de duurzaamheid van deze bedrijven te meten en op te volgen. We ontwikkelden indicatoren voor volgende ecologische duurzaamheidsthema's: biodiversiteit, watergebruik, waterkwaliteit en energiegebruik.

8.2.1. Een methode om indicatoren te ontwerpen (Hoofdstuk 5)

De methode past binnen een theoretisch kader van 'transitie'. Dat beschouwt duurzame ontwikkeling als een langdurig, complex en drastisch veranderingsproces. De methode omvat drie concrete stappen:

- een gedragen visie vormen;
- de belangrijkste principes van deze visie vertalen in concrete thema's die het begrip 'duurzaamheid' meer tastbaar maken op praktijkniveau;
- per thema relevante indicatoren ontwerpen.

In Vlaanderen werd een proces uitgewerkt waarbij zoveel mogelijk betrokkenen werkten aan een gedragen visie over de toekomst van de landbouw. Volgens deze visie liggen volgende belangrijke principes aan de basis van ecologisch duurzame landbouwsystemen:

- Een ecosysteem waarin alle organismen en hun interacties optimaal functioneren is stabiel, kent een minimale gevoeligheid voor verstoringen en kent een minimum aan verliezen. In een ecologisch optimaal landbouwecosysteem houdt men rekening met de specifieke fysische en biologische beperkingen ervan, sluit men kringlopen maximaal, zorgt men voor optimale bodem-, water- en luchtcondities en voorziet men een voldoende brede ecologische basis, door een maximaal behoud en gebruik van biodiversiteit.
- Duurzame landbouwsystemen minimaliseren hun negatieve milieu-impacten minstens tot op een niveau dat de draagkracht en het bufferend vermogen van de ecosystemen waarmee ze verbonden zijn niet overschrijdt. Werken aan de hoogst mogelijke eco-efficiëntie (de verhouding van gerealiseerde toegevoegde waarde tot de milieu-impact) is daarbij een belangrijk aspect.
- Duurzame landbouwsystemen maximaliseren hun positieve invloeden op het milieu, als dienst aan de maatschappij. Concreet gaat het dan om bv. blauwe

diensten (waterbeheer) of groene diensten (biodiversiteit, natuur en landschap).

Deze belangrijke principes werden vertaald in drie relevante thema's voor ecologische duurzaamheid van Vlaamse landbouwbedrijven: (i) gebruik van inputs (nutriënten, energie, water en gewasbeschermingsmiddelen), (ii) behoud van natuurlijke hulpbronnen (bodem-, water- en luchtkwaliteit) en (iii) biodiversiteit.

Wanneer bestaande indicatoren uit de (wetenschappelijke) literatuur pasten binnen de vooropgestelde visie en afgeleide thema's, werden ze in eerste instantie weerhouden. Daarna toetsten we deze indicatoren aan extra kwaliteitscriteria op vlak van relevantie, gevoeligheid, herhaalbaarheid, haalbaarheid, plaatsbaarheid en begrijpbaarheid.

Wanneer over bepaalde thema's weinig of geen literatuur beschikbaar was, deden we een beroep op experts en betrokkenen om indicatoren te ontwerpen, of werd er nieuw fundamenteel onderzoek uitgevoerd. Vooraleer een indicator finaal werd weerhouden, legden we hem voor aan een klankbordgroep van experts en betrokkenen om het ontwerp en de uitkomst van de indicator te valideren.

We pasten deze methode toe om indicatoren te ontwerpen voor biodiversiteit, watergebruik, waterkwaliteit en energiegebruik.

We raden aan dat de drie stappen van de beschreven methodologie (van visie over thema's naar indicatoren) doorlopen worden bij de ontwikkeling van indicatoren. Op die manier zorgt men ervoor dat indicatoren worden geselecteerd op basis van hun wetenschappelijke waarde en relevantie en vermijdt men de selectie van indicatoren enkel op basis van bv. beschikbaarheid van gegevens.

8.2.2. Indicatoren voor biodiversiteit (Hoofdstuk 2)

Biodiversiteitsindicatoren moeten aan verschillende eisen voldoen, afhankelijk van de vooropgestelde doelstellingen en het geografische niveau (bv. perceel – bedrijf – regio – land) waarop men ze toepast. Een optimaal indicatorsysteem voor biodiversiteit is hiërarchisch gestructureerd over verschillende geografische niveaus en doelstellingen heen en houdt hierbij rekening met de onderlinge relaties.

Het oorspronkelijke doel van deze studie was het ontwerpen van indicatoren die toelaten om Vlaamse landbouwbedrijven te beoordelen op vlak van het behoud en duurzaam gebruik van biodiversiteit en die tevens bruikbaar zijn om

landbouwers een inzicht te verschaffen in verschillende maatregelen die het management op het vlak van biodiversiteit op hun bedrijf duurzamer maken.

Een belangrijk aspect – en tevens een grote moeilijkheid – bij dergelijke beoordeling, is de relatie tussen de managementmaatregelen die worden genomen op bedrijfsniveau en de biodiversiteit op regionaal niveau. Daarom is het in de eerste plaats noodzakelijk om veranderingen in biodiversiteit op het regionale niveau te kunnen aantonen en evalueren. Vandaar dat we ons in deze studie voornamelijk richtten op het ontwikkelen van biodiversiteitsindicatoren op regionaal niveau, indicatoren die veranderingen in biodiversiteit gerelateerd aan landbouwlandschappen in Vlaanderen kunnen weergeven.

Een beoordelingssysteem voor biodiversiteit op bedrijfsniveau houdt best zo veel mogelijk rekening met de relatie tussen managementmaatregelen op bedrijfsniveau en hun effect op biodiversiteit op regionaal niveau.

In een eerste studie ontwikkelden we indicatoren voor de diversiteit tussen en binnen landbouwgewassen in Vlaanderen. We gebruikten de Shannon en Evenness diversiteitsindices als indicatoren voor de diversiteit tussen gewassen. Genetische diversiteit binnen drie gewassen werd eveneens geschat aan de hand van deze diversiteitsindices, maar ook aan de hand van de verwantschapscoëfficiënt, die de paarsgewijze genetische verwantschap tussen rassen weergeeft. De resultaten van deze studie toonden aan dat ondanks een felle toename van het aantal gewassen tussen 1950 en 2002, de gewasdiversiteit in Vlaanderen tijdens deze periode niet is gestegen. Dit wordt verklaard door de toenemende dominantie van een beperkt aantal gewassen, voornamelijk van maïs. En specifiek voor maïs wezen de indicatoren op een daling van de genetische diversiteit binnen dit gewas tussen 1980 en 2002.

Gezien het belang van genetische diversiteit van landbouwgewassen voor een duurzame landbouw en gezien het feit dat de indicatoren wijzen op een (gewasafhankelijke) daling van deze genetische diversiteit in Vlaanderen, zouden maatregelen moeten genomen worden om deze diversiteit te behouden, ten minste tot op z'n huidige niveau. De officiële rassenproeven zouden een geschikt platform kunnen zijn dat over dit probleem waakt.

Genetische diversiteit van landbouwgewassen zou in Vlaanderen in de toekomst meer gedetailleerd moeten opgevolgd worden en zou moeten in rekening gebracht worden bij het ontwerpen van nieuwe en duurzame landbouwsystemen.

In een tweede studie stelden we een objectieve, statistische methode voor om indicatorsoorten voor biodiversiteit binnen Vlaamse landbouwecosystemen en hun natuurlijke omgeving te selecteren. Als voorbeeld pasten we deze methode

toe om indicatorsoorten te selecteren voor de diversiteit aan akker- en graslandvogels.

Per Vlaamse ecoregio⁸ beschouwden we de 1km² hokken waarbinnen men inventariseerde in het kader van de Vlaamse Broedvogelatlas. Uit een lijst van 45 akker- en graslandvogels werd een soort geselecteerd als significante indicatorsoort, wanneer de gemiddelde soortenrijkdom van de 1 km² hokken waar deze soort voorkwam systematisch hoger was dan de gemiddelde soortenrijkdom van de hokken waar de soort niet voorkwam. Bijkomende selectiecriteria waren (i) dat de indicatorsoort niet te zeldzaam of te algemeen is (d.w.z. in minder dan 20% of meer dan 80% van de hokken voorkomend) en (ii) dat het gemiddelde landbouwareaal van de hokken waar de soort voorkwam hoger is dan het gemiddelde landbouwareaal van de hokken waar de soort niet voorkwam. Uiteindelijk werden binnen elke ecoregio de drie soorten weerhouden die gerelateerd waren aan de hoogste soortenrijkdom van akker- en graslandvogels.

Populatie-trends van deze geselecteerde indicatorsoorten zouden veranderingen in de diversiteit van akker- en graslandvogels in verschillende Vlaamse ecoregio's kunnen weergeven. Daarenboven kan men de ecologische kennis over de kwaliteit, kwantiteit en configuratie van de habitats van elke indicatorsoort gebruiken om een regiospecifiek management te plannen en/of te evalueren.

Het is onwaarschijnlijk dat een indicatorsoort uit één bepaalde taxonomische groep (bv. vogels) voldoende informatie kan verschaffen over de soortenrijkdom van andere taxonomische groepen, laat staan over biodiversiteit in z'n geheel. Het is daarom belangrijk dat de lijst met geselecteerde indicatorsoorten voor vogels kan worden uitgebreid met indicatorsoorten uit andere taxonomische groepen. Dit zal echter moeten gepaard gaan met een veel uitgebreidere monitoring – en gerelateerde ondersteuning – dan momenteel in Vlaanderen mogelijk is.

8.2.3. Indicatoren voor watergebruik (Hoofdstuk 6)

We ontwikkelden twee indicatoren om het watergebruik op Vlaamse landbouwbedrijven te evalueren: waterefficiëntie en het gebruik van alternatieve waterbronnen. Voor melkveebedrijven wordt waterefficiëntie berekend als de hoeveelheid geproduceerde melk (liter) per eenheid water op het bedrijf verbruikt (m³). Het gebruik van alternatieve waterbronnen geeft de

⁸ Een ecoregio groepeerde gebieden die homogeen worden beschouwd op het vlak van geologische, geomorfologische, grondwater- en oppervlaktewater kenmerken en gerelateerde bodemtypes.

inspanningen van de landbouwer weer om regenwater, ondiep grondwater of oppervlaktewater te gebruiken als alternatieven voor diep grondwater en leidingwater. De indicator wordt berekend als een gewogen gemiddelde van de aandelen regenwater (%RW), oppervlaktewater (%OW) en ondiep grondwater (%OGW) in het totale waterverbruik: gebruik van alternatieve waterbronnen = $0.44 \%RW + 0.34 \%OW + 0.22 \%OGW$.

Dit onderzoek heeft aangetoond dat, ondanks de toenemende aandacht voor de waterproblematiek in Vlaanderen, er bitter weinig cijfergegevens over waterverbruik op landbouwbedrijven beschikbaar zijn. In vele gevallen kent men enkel het verbruik van leidingwater en zijn geen cijfers gekend voor regenwater, oppervlaktewater en grondwater. Nochtans zijn deze gegevens essentieel voor het evalueren van waterverbruik op landbouwbedrijven. Bovendien zouden ze de landbouwer zelf veel inzicht kunnen verschaffen over het watermanagement op zijn bedrijf.

8.2.4. Indicatoren voor waterkwaliteit (Hoofdstuk 6)

Om het thema waterkwaliteit te beoordelen, beschouwden we de mogelijke verontreiniging van oppervlakte- en grondwater door geloosd bedrijfsafvalwater. De beoordeling was gebaseerd op een vergelijking van het management van de landbouwer met de Beste Beschikbare Technieken (BBT) voor afvalwaterbeheer op landbouwbedrijven. Voor melkveebedrijven werd de indicatorscore berekend als het gemiddelde van de scores voor drie beschouwde types van afvalwater: (i) afvalwater van melkinstallatie/koeltank, (ii) met mest bevuild afvalwater (melkstal/kalverboxen/ vaste mestopslag) en (iii) sapverliezen en overige run-off van sleufsilos.

Aangezien we slechts weinig (wetenschappelijke) informatie vonden over indicatoren voor duurzaam watergebruik op niet-geïrrigeerde melkveebedrijven, deden we een beroep op experts op het vlak van watergebruik op landbouwbedrijven in Vlaanderen. Zij waren verbonden aan volgende instellingen: AMINAL afdeling Water, Provinciaal Onderzoeks- en Voorlichtingscentrum voor Land- en Tuinbouw (POVLT), Provinciaal Proefcentrum voor de Groenteteelt (PCG) en Proefcentrum voor de Sierteelt (PCS). Aan de hand van een aantal werkvergaderingen werden de indicatoren opgesteld en verfijnd.

8.2.5. Indicatoren voor energiegebruik (Hoofdstuk 3)

We werkten twee indicatoren uit om het energiegebruik op Vlaamse landbouwbedrijven te beoordelen: energie-efficiëntie en het gebruik van

hernieuwbare energiebronnen. Energie-efficiëntie relateert de geproduceerde hoeveelheid producten aan de gebruikte hoeveelheid energie. We berekenden energie-efficiënties voor een representatieve groep van Vlaamse gespecialiseerde melkvee-, varkens- en akkerbouwbedrijven. We stelden vast dat het indirecte energieverbruik - voornamelijk vervat in minerale meststoffen en krachtvoerders - een belangrijk aandeel had (tot 70%) in het totale energieverbruik op de onderzochte bedrijven. Diesel vormde de belangrijkste directe energieverbruikspost. Voor melkvee- en akkerbouwbedrijven zagen we dat gedurende de periode 1989-1990 tot 2000-2001 het totale energieverbruik per ha wezenlijk daalde; op varkensbedrijven was het energieverbruik per mestvarkenequivalent in 1997-1998 vergelijkbaar met dat in 1989-1990. De meest energie-efficiënte melkvee- en varkensbedrijven waren intensieve bedrijven, die een hoge productie combineerden met een laag energieverbruik en die een bruto toegevoegde waarde per eenheid product realiseerden vergelijkbaar met of zelfs hoger dan het gemiddelde.

Gebaseerd op de energie-efficiënties van de 5% beste bedrijven uit de dataset, stelden we richtwaarden voor van 35 l melk 100 MJ⁻¹ en 7,5 kg levend varken 100 MJ⁻¹, respectievelijk voor Vlaamse melkvee- en varkensbedrijven. Op akkerbouwbedrijven bleek de energie-efficiëntie in hoge mate afhankelijk te zijn van de gewasrotatie; de indicator zou dus best berekend worden op perceelsniveau, voor elk gewas afzonderlijk.

Uit dit onderzoek bleek dat voor de onderzochte bedrijfstypes het indirect energieverbruik over het algemeen groter is dan het direct energieverbruik. Het is dan ook belangrijk om dit aspect te meten op Vlaamse landbouwbedrijven en om er over te communiceren met de landbouwers.

Naast de hoeveelheid gebruikte energie speelt ook de vorm ervan een cruciale rol: hernieuwbare energiebronnen kunnen bezwaarlijk over dezelfde kam geschoren worden als fossiele brandstoffen. De indicator 'gebruik van hernieuwbare energiebronnen' geeft het aandeel hernieuwbare energie weer in het totale directe energieverbruik van een bedrijf. Hoewel slechts weinig Vlaamse landbouwbedrijven momenteel al gebruik maken van hernieuwbare energiebronnen, wordt algemeen erkend (ook door de landbouwers) dat dit aspect in de toekomst wel belangrijker zal worden (Hoofdstuk 6).

8.2.6. Eco-efficiëntie (Hoofdstuk 4)

Een belangrijk principe van ecologische duurzaamheid is het werken aan de hoogst mogelijke eco-efficiëntie. Dit is een managementbenadering die op de Rio conventie in 1992 werd erkend als een manier voor bedrijven om bij te dragen aan duurzame ontwikkeling. Eco-efficiëntie houdt in dat men tracht om meer te

produceren met een lager verbruik van grondstoffen en/of met een lagere milieu-impact.

We maakten deze managementtechniek tot op zekere hoogte concreet op Vlaamse landbouwbedrijven en dit aan de hand van de ontwikkelde ecologische duurzaamheidsindicatoren (bv. energie-efficiëntie).

In een specifieke gevalstudie bepaalden we de eco-efficiënties van Vlaamse melkveebedrijven uit een representatieve set. Eco-efficiëntie werd daarbij bepaald aan de hand van de combinatie van stikstofefficiëntie (l melk kg^{-1} N overschot) en energie-efficiëntie (l melk 100MJ^{-1}). Deze studie toonde aan dat de eco-efficiënties van energie- en stikstofgebruik eenzelfde positief verloop kenden tussen 1989-1990 en 2000-2001. De melkveebedrijven die werkten aan de hoogste eco-efficiëntie werden gekarakteriseerd door een hogere melkproductie (per koe en per ha), een lager stikstof (N) overschot, een lager energiegebruik en een hogere bruto toegevoegde waarde.

Deze resultaten tonen aan dat op de onderzochte melkveebedrijven hogere eco-efficiëntie en goede economische prestaties vaak hand in hand gaan. We raden aan om dergelijke bevindingen consequent en duidelijk te communiceren naar landbouwers, aangezien zij hebben aangegeven dat ze het heel belangrijk vinden om de economische winst te zien bij het evalueren en mogelijk verbeteren of toepassen van (ecologisch gerelateerde) managementaspecten (Hoofdstuk 6).

8.2.7. Conclusie

In de eerste onderzoeksfase ontwierpen we indicatoren voor volgende ecologische duurzaamheidsthema's: biodiversiteit, watergebruik, waterkwaliteit en energiegebruik. Deze indicatoren maken 'duurzaamheid' concreet op Vlaamse landbouwbedrijven en laten toe om de duurzaamheid van deze bedrijven te meten en op te volgen.

De toegepaste methode wordt gekenmerkt door een transdisciplinaire aanpak en past binnen een conceptueel kader van 'visie → thema's → indicatoren'.

8.3. Fase 2: indicatoren aggregeren (Hoofdstuk 5)

In de tweede onderzoeksfase aggregateerden we de voorgestelde indicatoren in een integrale duurzaamheidsmonitor.

8.3.1. Een methode om indicatoren te aggregeren

De toegepaste methode bestaat uit drie stappen:

- richtwaarden definiëren om indicatorwaarden te herschalen naar scores tussen 0 en 100;
- gewichten voor de indicatoren definiëren;
- de indicatorscores aggregeren.

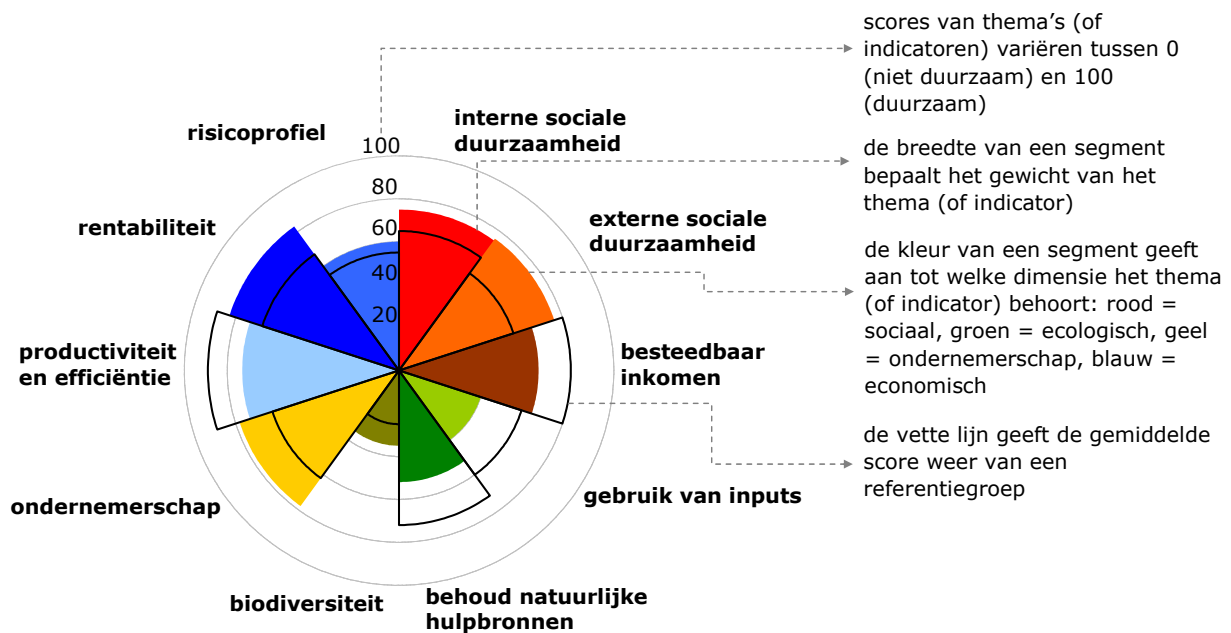
In de eerste stap definieerden we voor de ontwikkelde indicatoren minimum en maximum richtwaarden; deze laten toe om de indicatorwaarden te herschalen in scores tussen 0 (voor een slechtst mogelijke situatie) en 100 (voor veronderstelde maximale duurzaamheid). Voor de ecologische indicatoren beschreven in de voorgaande sectie, bepaalden we richtwaarden aan de hand van:

- de indicatorwaarden van een referentiegroep van vergelijkbare bedrijven (voor de indicatoren voor energiegebruik en watergebruik): de 10% beste en 10% slechtste bedrijven uit de dataset bepalen de respectieve maximum en minimum richtwaarden. Tussenliggende indicatorwaarden worden omgezet in lineair tussenliggende scores.
- Best Beschikbare Technieken (BBT, voor de indicatoren voor waterkwaliteit): de indicatorscore wordt bepaald aan de hand van een vergelijking van de toegepaste managementmaatregelen op een bedrijf met de BBT, die de maximum richtwaarde definiëren.
- wetenschappelijke of wettelijk gebaseerde standaarden: een N-overschot van 150 kg ha^{-1} (maximum richtwaarde) of lager beantwoordt aan de wettelijke standaarden volgens de Europese nitraatrichtlijn (Neuens et al., 2006).

In een tweede stap kenden we aan elke indicator een gewicht toe. Hierbij hielden we rekening met de gelijkwaardigheid van de ecologische, economische en sociale dimensie van duurzaamheid. Gelijklopend aan dit principe, beschouwden we binnen een bepaald duurzaamheidsthema alle indicatoren eveneens gelijkwaardig, behalve wanneer er duidelijk aantoonbare indicaties waren – gebaseerd op literatuuronderzoek of expertenmening – dat een bepaalde

indicator effectief belangrijker kan geacht worden dan andere indicatoren om een bepaald thema te beoordelen.

Tenslotte werden de indicatorscores geaggregeerd in een duurzaamheidsmonitor, MOTIFS (*Monitoring Tool for Integrated Farm Sustainability*). Figuur 8.3 geeft een overzichtsbeeld van MOTIFS waarbij de ecologische thema's samen met economische en sociale thema's en het thema ondernemerschap (ontwikkeld door Steunpunt Duurzame Landbouw, 2006) grafisch worden weergegeven.



Figuur 8.3. MOTIFS, een overzichtsbeeld

We hechten belang aan de gebruiksvriendelijkheid en het communicatief sterke karakter van MOTIFS. Daarom is MOTIFS een hiërarchisch gestructureerd systeem: op niveau 1 (Figuur 8.3) wordt een overzicht gegeven van de globale duurzaamheid van een bedrijf. Op niveau 2 geven drie radardiagrammen een overzicht van de duurzaamheid binnen een specifieke duurzaamheidsdimensie (economisch, ecologisch of sociaal) en op niveau 3 worden indicatorscores per thema geaggregeerd in individuele thema-radardiagrammen. Op die manier kan een landbouwer starten met een globaal overzicht van de duurzaamheid op zijn bedrijf en zo verder inzoomen op onderliggende thema's en indicatoren. Een ander aspect dat het systeem gebruiksvriendelijk en communicatief sterk maakt, is de mogelijkheid om per thema de gemiddelde score van een vergelijkbare groep van bedrijven weer te geven.

Als een eerste toepassing gebruikten we MOTIFS op een individueel Vlaams melkveebedrijf. Sommige indicatoren en thema's werden niet gemeten op het bedrijf, maar toch namen we deze expliciet op in het systeem om te

benadrukken dat de lijst met indicatoren die wel werden gemeten niet limitatief is en dat het resultaat dus geen volledige duurzaamheidsbeoordeling is. Bovendien kan dit de landbouwer bewust maken van het feit dat om bepaalde indicatoren te kunnen berekenen, hij extra gegevens zal moeten verzamelen.

We beschouwen MOTIFS als een geschikt instrument om bestaande systemen te optimaliseren, maar we moeten ons er van bewust zijn dat zelfs geoptimaliseerde systemen nog steeds niet duurzaam kunnen zijn. Deze systeemoptimalisatie is een eerste stap om duurzaamheid te vertalen naar concrete acties, maar om tot echt duurzame situaties te komen zullen we waarschijnlijk ook compleet nieuwe systemen moeten bedenken en ontwerpen (systeeminnovatie).

8.3.2. Conclusie

We ontwierpen een gebruiksvriendelijk en communicatief sterk systeem om geïntegreerde (ecologische én economische én sociale) duurzaamheid van melkveebedrijven te meten en op te volgen. Het systeem past in een goed onderbouwd methodologisch kader en is gebaseerd op een set van relevante indicatoren. Een transdisciplinaire aanpak waarbij we betrokkenen en experts consulteerden was een belangrijk onderdeel van het ontwikkelingsproces.

Onze aanpak werd gekarakteriseerd door een zeker pragmatisme (in de keuze van richtwaarden, gewichten, e.d.). We beschouwen deze pragmatische aanpak gerechtvaardigd binnen ons onderzoek, meer specifiek met onze tweede onderzoeksdoelstelling in gedachten: een instrument ontwikkelen dat aanzet tot effectieve acties, dat praktisch toepasbaar is en ook effectief toegepast wordt op Vlaamse landbouwbedrijven.

Gebruik van MOTIFS op 20 Vlaamse melkveebedrijven (Hoofdstuk 6)

Enkele duurzaamheidsindicatoren uit MOTIFS worden toegepast op 20 Vlaamse melkveebedrijven gelegen in het Meetjesland en het Brugse Ommeland, om duurzaamheid te meten en communicatie en uitwisseling van kennis tussen de deelnemende landbouwers te stimuleren. Deze 20 bedrijven nemen deel aan het Leader+ project 'Sterk met Melk' (2006-2008). Leader+ (*Liaisons Entre Actions de Développement de l'Economie Rurale*) is een initiatief gefinancierd door de Europese Unie dat plattelandsactoren wil aanzetten om na te denken over het potentieel van hun gebied en hen wil ondersteunen in de realisatie van geïntegreerde en innovatieve projecten.

Een projectleider bezoekt elk deelnemend bedrijf om de drie maanden en verzamelt gegevens, berekent de indicatoren en bespreekt de resultaten met elke landbouwer afzonderlijk. Daarenboven organiseert de projectleider rond elke thema een discussiegroep, waarbij de deelnemende landbouwers hun resultaten onderling kunnen vergelijken, samen met de projectleider en een expert ter zake. Een stuurgroep met daarin vertegenwoordigers van verschillende organisaties gerelateerd aan melkveehouderij en landbouw komt twee keer per jaar samen en geeft advies over de vorm en inhoud van het project.

Gedurende de eerste periode (2006-2007) heeft het project vooral de nadruk gelegd op ecologische duurzaamheidsaspecten: gebruik van nutriënten, energie en water en waterkwaliteit. In 2008 zullen eveneens economische en sociale aspecten beschouwd worden.

Het valideren van de eindgebruikswaarde van MOTIFS is van essentieel belang voor een continue optimalisatie en verbetering van het systeem. Daarom moedigen we de toepassing van het systeem aan op zoveel mogelijk praktijkbedrijven in Vlaanderen, ook al zijn nog niet alle indicatoren tot in detail uitgewerkt.



8.4. Fase 3+4: Validatie en suggesties (Hoofdstuk 6)

In de finale fasen van het onderzoek ontwikkelden we een gedetailleerde validatiemethode en pasten deze toe om MOTIFS en de ecologische duurzaamheidsindicatoren te valideren. Daarnaast deden we enkele voorstellen om het ontwerp van MOTIFS en de effectieve toepassing ervan in de praktijk te verbeteren.

8.4.1. Een validatiemethode

Met een validatie gaan we na of een indicator of beoordelingssysteem voldoende nauwkeurig is om effectief te beantwoorden aan de vooropgestelde criteria en doelstellingen. Een andere belangrijke eigenschap is de geloofwaardigheid van een indicator. Die drukt het vertrouwen uit van potentiële eindgebruikers in de indicator en hun bereidwilligheid om deze effectief in de praktijk te gebruiken.

De voorgestelde validatiemethode bestaat uit twee stappen:

- een evaluatie van de nauwkeurigheid van MOTIFS en de ecologische indicatoren, bestaande uit een validatie van hun wetenschappelijke degelijkheid en van hun resultaat;
- een evaluatie van de geloofwaardigheid van MOTIFS en de ecologische indicatoren, bestaande uit een validatie van hun eindgebruikswaarde.

8.4.1.1. Evaluatie van de nauwkeurigheid

Met de evaluatie van de nauwkeurigheid gaan we na in welke mate MOTIFS en de ecologische indicatoren voldoen aan de vooropgestelde doelstellingen en het vooropgestelde praktische gebruik. In onze studie zijn de vooropgestelde doelstellingen van de ontwikkelde ecologische duurzaamheidsindicatoren: (i) duurzaamheid concreet maken op Vlaamse landbouwbedrijven, (ii) duurzaamheid van Vlaamse landbouwbedrijven meten en opvolgen en (iii) landbouwers motiveren en begeleiden bij het nemen van effectieve acties naar een duurzamere bedrijfsvoering. MOTIFS werd ontworpen met de bedoeling te dienen als een effectief beslissingsinstrument en communicatiemiddel.

We valideerden de nauwkeurigheid van MOTIFS en de ecologische indicatoren aan de hand van klankbordgroepen, waarbij experts en betrokkenen de voorgestelde indicatoren beoordeelden op vlak van hun wetenschappelijke degelijkheid, juistheid van de resultaten, gebruik van (beschikbare) gegevens, gebruikte richtwaarden en toegekend gewicht. Deze transdisciplinaire benadering werd ook toegepast om het ontwerp van MOTIFS in z'n geheel te valideren, waarbij in een klankbordgroep de methodologische keuzes met betrekking tot de

aggregatie van de indicatoren (visuele vs. numerieke integratie) en bepaalde aspecten van de visuele voorstelling (radardiagram vs. staafdiagram) werden besproken. Er werden eveneens experts betrokken tijdens het ontwerp van sommige indicatoren (voor watergebruik en waterkwaliteit).

We valideerden de nauwkeurigheid van de indicatoren eveneens door zoveel mogelijk bestaande kennis te compileren uit wetenschappelijke literatuur en door de methoden en resultaten van de ontwikkelde indicatoren zelf te publiceren in wetenschappelijke tijdschriften.

We beschouwen het raadplegen van betrokkenen en experts als heel belangrijk bij de ontwikkeling van een indicator of beoordelingssysteem, voornamelijk met betrekking tot de effectieve toepassing ervan in de praktijk. Deze transdisciplinaire benadering laat niet enkel toe om de kloof tussen wetenschap en praktijk in grote mate te overbruggen, het zorgt ook voor een breed draagvlak voor MOTIFS bij de belanghebbenden, die bij de ontwikkeling van het systeem werden betrokken.

8.4.1.2. Evaluatie van de geloofwaardigheid

De geloofwaardigheid van een systeem bepaalt de mate van vertrouwen dat potentiële eindgebruikers erin hebben en is dus een indicatie van hun bereidheid om het systeem effectief in de praktijk te gebruiken. Deze evaluatie omvat een beoordeling van de eindgebruikswaarde van het systeem.

We ontwikkelden een test om de geloofwaardigheid van MOTIFS en de ontwikkelde ecologische indicatoren gelijktijdig te beoordelen. Deze test evalueert drie aspecten: (i) de eindgebruikswaarde van de ontwikkelde ecologische indicatoren als beslissingsinstrumenten, (ii) de eindgebruikswaarde van MOTIFS als beslissings- en communicatie-instrument en (iii) de bereidheid van potentiële eindgebruikers om MOTIFS effectief in de praktijk te gebruiken. Deze test maakte gebruik van semi-gestructureerde interviews.

De antwoorden van de potentiële eindgebruikers (dit zijn enerzijds Vlaamse melkveehouders en anderzijds 'duurzaamheidsadviseurs') bevestigden dat de indicatoren waardevolle instrumenten zijn om beslissingen en effectieve acties te nemen. MOTIFS werd beschouwd als een bruikbaar instrument om het begrip 'duurzaamheid' concreet te maken voor Vlaamse melkveebedrijven. Anderzijds vonden de respondenten dat bijkomende informatie noodzakelijk was om de meest geschikte managementkeuzes te kunnen maken en om effectief actie te kunnen ondernemen.

Gebaseerd op de resultaten van deze test veranderden we enkele specifieke indicatoren. Zo splitsten we de indicator 'energie-efficiëntie' in twee verschillende

indicatoren 'directe energie-efficiëntie' en 'indirecte energie-efficiëntie', omdat dit voor de eindgebruikers duidelijker was, zonder afbreuk te doen aan de wetenschappelijke waarde van de beoordeling.

We beschouwen de mening van potentiële eindgebruikers van MOTIFS van groot belang voor de effectieve praktische toepassing van het systeem. Elke suggestie die eindgebruikers maken zou moeten worden getest op z'n wetenschappelijke waarde en relevantie binnen de gedefinieerde visie en afgeleide thema's. Wanneer een dergelijke suggestie de gebruiksvriendelijkheid van het systeem verbetert en tegelijkertijd past binnen de onderliggende theorie, dan moet een aanpassing van het systeem overwogen worden. Op die manier kan men de duurzaamheidsmonitor continue updaten en verbeteren.

De validatie van de eindgebruikswaarde van MOTIFS toonde eveneens aan dat sommige indicatoren en het gebruik van een radardiagram nieuw zijn voor landbouwers en adviseurs. Het kan van potentiële eindgebruikers dus enige tijd vergen om de indicatoren goed te begrijpen en gewoon te worden aan deze nieuwe manier van voorstellen.

We moeten hiermee rekening houden wanneer MOTIFS voor de eerste keer wordt voorgesteld aan potentiële eindgebruikers. Deze vaststellingen wijzen er ook op dat er best een gedetailleerde training of begeleiding voorzien is bij het gebruik van het systeem.

De ondervraagde landbouwers waren bijzonder enthousiast over het lerend effect dat verbonden is aan het praktische gebruik van MOTIFS in het 'Sterk met Melk' project. Vooral het deelnemen aan de discussiegroepen waar landbouwers onderling resultaten kunnen uitwisselen en technische aspecten van hun bedrijfsmanagement onderling kunnen bespreken, vonden de meeste deelnemers heel interessant en leerzaam.

MOTIFS kan evolueren van een meetsysteem naar een echt managementsysteem, wanneer we het leerproces van terugkoppelen, analyse en reflectie structureel kunnen inbouwen in de praktische toepassing ervan.

De interviews toonden aan dat er een draagvlak bestaat voor het concept 'duurzaamheid' bij de ondervraagde landbouwers en landbouwadviseurs en dat ze het belangrijk vinden om te streven naar een duurzamer management. MOTIFS werd hierbij beschouwd als een nuttig instrument met een meerwaarde t.o.v. andere vormen van bedrijfsadvies. De potentiële eindgebruikers schenen vertrouwen te hebben in het systeem en de informatie die het levert, wat de geloofwaardigheid van MOTIFS bevestigt.

Zowel landbouwers als landbouwadviseurs zeiden bereid te zijn MOTIFS in de praktijk toe te passen op regelmatige basis. Een kritieke succesfactor hierbij is echter de gebruiksvriendelijkheid van het systeem: indicatorwaarden, scores en radardiagrammen moeten gemakkelijk beschikbaar gemaakt worden, en dit met minimale extra inspanningen. Daarom werkt de eenheid Landbouw en Maatschappij van het ILVO aan een softwarepakket dat toelaat om MOTIFS te implementeren in reeds bestaande boekhoudprogramma's die vandaag gebruikt worden door bedrijfsadviseurs.

De validatie toonde ook aan dat landbouwers niet bereid zijn om MOTIFS op hun bedrijf toe te passen, als ze daarbij alle berekeningen en de interpretatie van de resultaten zelf moeten doen. Zij oordeelden dat in het ideale geval MOTIFS gebruikt wordt in samenkomsten met hun bedrijfsbegeleider, om de sterktes en zwaktes van hun bedrijf te belichten en dat verschillende landbouwers daarna ook samenkomen in een discussiegroep om verschillende technische aspecten van hun bedrijfsmanagement te bespreken en om van elkaar te leren.

Dit toont aan dat een effectieve toepassing van MOTIFS op Vlaamse landbouwbedrijven best kan gebeuren wanneer het systeem aan landbouwers wordt geïntroduceerd via bedrijfsbegeleiders. Zij zijn het best onderlegd om in vertrouwen verschillende duurzaamheidsaspecten met de landbouwers te bespreken, om extra informatie te verschaffen en advies te verlenen en om discussiegroepen tussen landbouwers te organiseren.

8.4.2. Conclusie

We ontwikkelden een gedetailleerde validatieprocedure en pasten deze toe om MOTIFS en de voorgestelde ecologische duurzaamheidsindicatoren te valideren. De voorgestelde procedure kan volgens ons ook toegepast worden om andere duurzaamheidsindicatoren en andere beoordelingssystemen te valideren. We vonden de methode heel bruikbaar, niet alleen om de wetenschappelijke degelijkheid van MOTIFS en de indicatoren na te gaan, maar ook om de bereidwilligheid te testen van potentiële eindegebruikers om het systeem effectief in de praktijk toe te passen. Dankzij dergelijke validatie kan men het systeem en de praktische toepassing ervan continue verbeteren en updaten.

Een meer duurzame landbouwproductie kan enkel gerealiseerd worden wanneer men de theoretische doelstellingen kan vertalen in effectieve praktische maatregelen. Een eerste stap is het ontwerpen van een systeem dat deze vertaling toelaat, maar een tweede belangrijke stap is het systeem ook effectief in de praktijk te implementeren. De voorgestelde validatieprocedure is volgens ons nuttig voor beide stappen en is een eerste poging om duurzaamheid echt operationeel te maken op Vlaamse landbouwbedrijven.

We raden aan om elk (nieuw ontwikkeld) beoordelingssysteem en elke duurzaamheidsindicator te valideren. We beschouwen deze validatie als een essentieel onderdeel van hun ontwikkelingsproces.

Gebaseerd op de validatie van de eindgebruikswaarde, besluiten we dat MOTIFS een effectief beoordelings- én managementinstrument kan zijn voor duurzaamheid op Vlaamse landbouwbedrijven. MOTIFS bezit belangrijke eigenschappen die zouden moeten aanwezig zijn in elk indicatorsysteem:

- Positioneren: MOTIFS laat toe om de sterke en zwakke punten van een landbouwbedrijf aan te duiden;
- Informeren: MOTIFS kan landbouwers helpen effectieve acties te ondernemen en beslissingen te nemen, bv. met betrekking tot nieuwe investeringen;
- Leren: MOTIFS kan landbouwers helpen om tot inzichten in hun landbouwsysteem te komen. Dit lerend effect kan versterkt worden door een optimale praktische toepassing van het systeem;
- Communiceren: MOTIFS laat toe om op een concrete en tastbare manier te communiceren over een moeilijk te definiëren onderwerp als 'duurzaamheid'.

Rekening houdend met deze eigenschappen willen we benadrukken dat men MOTIFS best toepast als een lerend, informerend en communicerend instrument en niet als een controle-instrument.

8.5. Om te eindigen

We denken dat we met dit onderzoek een instrument hebben ontwikkeld dat potentieel kan bijdragen aan een (meer) duurzame Vlaamse landbouw. Potentieel, aangezien de bijdrage uiteindelijk afhangt van de effectieve toepassing van het systeem op Vlaamse landbouwbedrijven.

We hopen dan ook dat het resultaat van dit onderzoek mag verder leven in wetenschap en praktijk, dat het z'n weg mag vinden naar Vlaamse landbouwers, dat MOTIFS nog verder mag verbeterd en vervolledigd worden en dat de effectieve praktische toepassing van het systeem in het 'Sterk met Melk' project een voorbeeld voor anderen mag zijn die proberen om duurzaamheid echt operationeel te maken.

Tenslotte nog dit. Een duurzame landbouwsector kan enkel bestaan binnen een duurzame maatschappij. Duurzaamheid in de praktijk brengen is dus niet enkel een taak voor de Vlaamse landbouwers, maar steunt op een gedeelde verantwoordelijkheid van de gehele maatschappij.

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Scientific curriculum vitae

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In February 2003, she started as scientific researcher at the Policy Research Centre for Sustainable Agriculture, where she worked on the development of indicators for ecological sustainability of Flemish agriculture.

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Master thesis

Meul, M. 2000. Computercartografie van bodemtextuur onder niet-stationaire omstandigheden. Gevalstudie: Oost-Vlaamse leemstreek. Eindwerk voorgedragen tot het behalen van de graad van bio-ingenieur in het land- en bosbeheer.

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